Towards a better understanding of the natural flow regimes and streamflow characteristics of rivers of the Maritime Provinces

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2009

Canadian Technical Report of Fisheries and Aquatic Sciences 2843

Fisheries and Oceans | Pêches et Océans

Canada

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Cat. No. Fs. 97-6/2843E ISSN 0706-6457

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Correct citation for this publication:

Caissie, D. and S. Robichaud. 2009. Towards a better understanding of the natural flow regimes and streamflow characteristics of rivers of the Maritime Provinces. Can. Tech. Rep. Fish. Aquat. Sci. 2843: viii + 53p.

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ABSTRACT

Caissie, D. and S. Robichaud. 2009. Towards a better understanding of the natural flow regimes and streamflow characteristics of rivers of the Maritime Provinces. Can. Tech. Rep. Fish. Aquat. Sci. 2843: viii + 53p.

River hydrology is a key component in river engineering, river restoration, river resources planning as well as in the functioning of river ecosystems. As such, hydrological analyses play an important role not only in water resources projects but also in fish habitat and instream flow studies. In fact, hydrological attributes are increasingly being considered in fisheries projects, as they are recognised to significantly influence fish habitat and stream productivity.

Studies have shown the importance of river hydrology in ecological studies where they have described many key components of the natural flow regime. The natural flow regime is generally described using 5 broad categories: 1) magnitude of discharge, 2) frequency, 3) duration, 4) timing and 5) rate of change. These categories will also be used within the present study; however, specific flow metrics within each category will be selected and described. As such, this study will focus on flow metrics that best describe the natural flow regime and the hydrological characteristics of rivers within the Maritime Provinces.

In total, 55 hydrometrics stations were chosen for the analysis and parameters describing flow availability included, among others, the mean annual flow, median flow as well as mean monthly flows. A flow duration analysis was also conducted for each station to estimate the probability of exceedance of different flows throughout the year. Extreme events are also important in hydrology and these were studied by conducting a high and low flow frequency analyses. Following the frequency analysis, regional regression equations were calculated between many flow metrics and drainage basin area and comparisons were made between provinces.

RÉSUMÉ

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L'hydrologie des cours d'eau joue un rôle important dans l'aménagement et la restauration des rivières, dans l'utilisation des ressources hydriques ainsi que dans le fonctionnement des écosystèmes aquatiques. Alors, les analyses hydrologiques jouent un rôle important non seulement dans les projets de ressources hydriques, mais aussi pour l'habitat du poisson et l'évaluation du débit réservé. En fait, les caractéristiques hydrologiques sont de plus en plus considérées dans les projets halieutiques, comme ils sont reconnus pour influer l'habitat du poisson et la productivité des cours d'eau.

Des études ont montré l'importance de l'hydrologie dans des études écologiques où ils ont décrit de nombreux éléments clés du régime d'écoulement naturel. Le régime d'écoulement naturel est généralement décrite en utilisant 5 grandes catégories: 1) l'intensité du débit, 2) la fréquence, 3) la durée, 4) le calendrier des événements et 5) le taux de changement. Ces catégories seront également utilisées dans la présente étude, cependant, des caractéristiques hydrologiques spécifiques au sein de chaque catégorie seront sélectionnées et décrites. Cette étude se concentrera alors sur les paramètres hydrologiques qui décrivent le mieux le débit et le régime naturel hydrologique des cours d'eau des provinces Maritimes.

Au total, 55 stations hydrométriques ont été choisies pour l'analyse des caractéristiques hydrologiques décrivant la disponibilité en eau, entre autres, le débit moyen annuel, le débit médian ainsi que les débits mensuels moyens. Une analyse de débit classé a également été réalisée pour chaque station afin d'estimer la probabilité de dépassement des différents débits tout au long de l'année. Les évènements extrêmes sont également importants en hydrologie et ils ont été étudiés par une analyse de fréquence des débits de crues et des débits faibles. Suite à l'analyse de fréquence, des équations de régression régionales ont été calculées entre de nombreux paramètres de débits vs superficie des bassins versant et des comparaisons ont été effectuées entre les provinces.

1.0 INTRODUCTION

The fundamental understanding of the natural flow regime of rivers has always played an important role in hydrological studies; however, in recent years this understanding is becoming increasingly important as well, when conducting instream flow assessments. As such, hydrological events are important not only to water resource projects but also to fish habitat and fisheries management. Streamflow availability and variability can affect stream biota at different life stages. For example, salmonids can be affected by stream discharge such as high flows that increase mortalities or displacement (Elwood and Waters, 1969; Erman et al., 1988). Similarly, natural low flow events can affect fish movements, limit fish habitat and increased stress due to high water temperatures (Caissie, 2006a; Cunjak et al., 1993; Edwards et al., 1979). This study focuses on key hydrological variables and provides data on indices (that are easily calculated by both hydrologists and biologists) that best describe the natural flow regime of rivers within the Maritime Provinces. Such information will be useful when conducting hydrological and instream flow studies.

When dealing with instream flow evaluations, Tharme (2003) recognized over 200 methods around the world. These methods have been categorized into four different groups: 1) hydrological, 2) hydraulic rating, 3) habitat preference and 4) holistic approaches. Such methods have also been found to vary both in data requirements and complexity (Caissie and El-Jabi, 2003). The first step when conducting an instream flow evaluation (i.e., before the application of any instream flow methods) is to characterize the natural flow regime of the river under investigation. This characterization is important as studies have shown that the natural flow regime plays a key role in the functioning of river ecosystems. This concept has been described in the literature as the Natural Flow Paradigm (NFP, Poff et al., 1997) and where the natural flow regime is recognized as a key ecological component worth protecting. As a result, the natural flow regime has become the bench mark against

which managers evaluate acceptable levels of change when conducting instream flow studies. Therefore, a good understanding of the natural flow regime is a first step towards conducting better instream flow studies.

In order to apply the NFP concept, key hydrological indicators are required. These hydrological indicators have been described using five different groups (Poff et al., 1997): 1) magnitude of discharge, 2) frequency, 3) duration, 4) timing and 5) rate of change. In the present study, hydrological indices within each category were selected based on information provided in the study by Poff et al. (1997); however, indices were different than those used for studying hydrologic alteration by Richter et al. (1996). For example, the magnitude of discharge will include those parameters that are descriptive of the river hydrology. Flow characteristics, such as the mean annual flow (MAF, informative on water availability), mean monthly flows (distribution of flows within the year) as well as flow duration characteristics (temporal distribution of water availability) will be included within this category. The second group of indices will include frequency of discharge events and pertains mainly to the characterization of extreme events, i.e., peak flows, bankfull discharge (important for channel shape and form) and low flow events. Frequency of discharge plays an important role in instream flow studies; particularly low flow events as these events often occur during the need for water extractions. Also, high flows are essential to maintain the character of the river and for the flushing of fines.

The third group includes the quantification of the duration of specific events. The best method to describe the duration of events is the Peak Over Threshold (POT) or Deficit Below Threshold (DBT) approach. This approach, the analysis of information above (or below) a given threshold (Q_r), is known as a partial duration series approach and has been applied to both high and low flow events (Caissie and El-Jabi, 1991; Ashkar et al. 1998). The partial duration series approach has the advantage of analyzing not only the duration of the event (T_v), but also other relevant flow

characteristics, such as the magnitude or intensity (I_v) as well as the volume (D_v). Figure 1 provides an illustrative example of the DBT approach. The partial duration series approach also has the advantage of being able to analyze different flow statistics together, e.g., the analysis of flow magnitude, duration and volume of events using joint probability distribution functions (Savoie et al., 2004).

The forth group within the NFP includes the timing of events. In the present study, the timing of events will be looked at in terms of high and low flow events, which are best described by their relative frequencies. This analysis consists of determining when such events occurred over the period of record and by plotting histograms showing their relative frequencies. The last group of hydrological indicators includes the rate of change of river discharge (e.g., flashiness), which can be different among large and small river systems. Such streamflow characteristics are best described using hydrograph analyses. For instance, the rate of change in discharge initially increases during a particular event (also referred to as the rising limb of the hydrograph) and the rate of change is both a function of the amount of precipitation and drainage basin characteristics (e.g., forest cover, land use, etc.). The rising limb of the hydrograph generally occurs quite rapidly in comparison to the falling limb or baseflow recession (describing the decrease in discharge following the peak discharge). The baseflow recession part of the hydrograph usually occurs over a longer period and is best described using exponential functions.

Within the NFP concept, many hydrologic indices have been calculated in the past. For instance, recent studies have identified numerous indicators of hydrologic alteration (Olden and Poff, 2003), which characterized the structure of the flow regime and its variability. Most of these hydrologic indices fall within the 5 grouping of the NFP described by Poff et al. (1997). As such, they are used during hydrologic studies as well as instream flow evaluations. For example, Richter et al. (1996) identified 66 flow indices when looking at hydrologic alteration issues. Olden and Poff (2003)

identified 171 flow variables whereas Monk et al. (2007) described over 200 indices. With so many indices being used to describe the natural flow regime, it is becoming increasingly difficult to identify the most relevant of these hydrologic characteristics, i.e., those that best represent the river hydrology. There is a need to reduce the number of parameters being considered to a limited set of key indices. Consequently, we will focus on those indices that best describe the river hydrology and which are the most important when using hydrologically-based instream flow techniques (Caissie and El-Jabi 1995a and 1995b).

Within the present study, the natural flow regime was analysed and described to increase our understanding of streamflow availability and variability. The study focused on important hydrologic characteristics being measured at 55 hydrometric stations across the Maritime Provinces. Analysed flow characteristics under "magnitude of discharge" (group 1) included the mean annual flow, monthly flows as well as flow duration analysis. Regional equations for the mean annual flow and median flow were also calculated to provide information on water availability for ungauged basins. The frequency of high and low flow events (group 2) was also analysed and their corresponding regional flow equations were calculated. The "index of floods" approach was used to understand the relationship between low return floods (e.g., 2-year flood or the mean annual flood) to high return floods (e.g., 50-year). The timing of high and low flow events (group 4) was also calculated. These streamflow characteristics were then compared among provinces. Information was provided on indices (and ratios) describing streamflow characteristics that can be easily obtained (by both hydrologists and biologists) without necessarily carrying out complex calculations.

2.0 MATERIALS AND METHODS

2.1 Data and study region

The hydrological analysis was carried out using historical data from 55 hydrometric stations across the Maritime Provinces with 23 stations from New Brunswick (NB), 26 stations from Nova Scotia (NS) and 6 stations from Prince Edward Island (PEI) (Figure 2). All data used in the present study were collected from the HYDAT database (Environment Canada, 2003). Data extracted from HYDAT included daily and monthly discharges as well as extreme values, i.e., annual minimum and maximum discharges. The Mean Annual Flow (MAF) represents the mean of daily discharge throughout the calendar years. The MAF provides information on the water availability for a given river and drainage basin. Another relevant flow index and related to the mean annual flow was the water contribution or discharge per unit area. This flow statistic was obtained by dividing the MAF by the drainage area and expressing values in m^3/s per km^2 (when these flows are small, values are multiplied by 1000, thus expressing these flows as L/s per km^2 = $L/s/km^2$). Mean monthly flows (MMF) were also obtained for each hydrometric station by province. In order to compare values among sites, the MMFs were divided by the MAF and used as an index for monthly flows.

2.2 Flow duration analysis

Following the mean flow calculations, a flow duration analysis was conducted for each hydrometric station. This analysis provides information on the time that specific flows were exceeded within a given time period. A flow duration analysis is a non-parametric cumulative distribution function of daily discharges. It consists of ranking flows from the highest to the lowest values and then calculating their respective frequencies. A flow duration curve can be constructed by plotting the ranked flows against the calculated frequencies and corresponding flows of different frequencies (or percentiles) can thereafter be determined (e.g., 50% or median flow Q_{50}, 90% or Q_{90},

etc.). In the present study, the flow duration analysis was carried out using the FLODUR software (Caissie, 1991), which makes the necessary calculation using Environment Canada (HYDAT) flow data. Important flow characteristics, taken from the flow duration curve, were the Q_{50} or median flow (i.e., the flows that are exceeded 50% of the time) and the Q_{90}. The Q_{90} is a flow that is exceeded 90% of the time on the flow duration curve and represents a low flow value. The ratio of Q_{90} over Q_{50} is sometime used as an index of baseflow (i.e., higher values representing higher baseflow or more stable flow). The above flows were calculated and comparisons were made for different rivers within the Maritime Provinces.

2.3 Frequencies of high and low flows

Following the analysis of mean flows and flow duration analysis, extreme events were also considered within the present study. Extreme events consist of flows (both high and low flows) that are expressed as a function of recurrence intervals. Many distribution functions can be used to describe both floods and low flow frequencies and these have been described in previous studies (e.g., Kite, 2004; Bobee and Ashkar 1991; and others). For high flow events, the maximum daily discharge by year was extracted from the HYDAT database and fitted to a high flow distribution function, namely the 3-parameter lognormal distribution function in this case. The 3-parameter lognormal distribution function was chosen because it has previously been used with good success to describe floods within the Maritime Provinces (Environment Canada and New Brunswick Department of Municipal Affairs and Environment, 1987). For low flow events, the minimum daily discharge was extracted and fitted to a low flow distribution function. In the case of the low flow events, the 3-parameter Weibull distribution function was used and this distribution is the most common used distribution for studying low flows. The parameters for both distributions (i.e., the 3-parameter lognormal and 3-parameter Weibull) were estimated using the maximum likelihood method. To represent an estimate of high flows with a low recurrence interval, the Mean Annual Flood (QMF) was also calculated. The QMF was calculated

by taking the average of annual maximum discharge. Similarly, the average annual minimum discharge (or QML) was calculated to represent low flows with a low recurrence interval.

Flood frequency was analysed using the 3-parameter lognormal distribution function. All calculations were carried out in Minitab® (version 15.1.1.0) with parameters estimated using the Maximum Likelihood Method (MLM). The probability density function (PDF) of the 3-parameter lognormal function is given by:

$$f(x) = \frac{1}{\sqrt{2\pi}\sigma(x-\lambda)} \exp\left\{\frac{-[\ln(x-\lambda)-\mu]^2}{2\sigma^2}\right\} \quad (1)$$

where μ is the form parameter; σ is the scale parameter; and λ is the threshold parameter.

In hydrology, the cumulative distribution function (CDF) is most often used to represent flows of different recurrence intervals where the CDF for the 3-parameter lognormal distribution function is given by the following equation:

$$F(x) = \int_{-\infty}^{x} \frac{1}{\sqrt{2\pi}\sigma(t-\lambda)} \exp\left\{-\frac{[\ln(x-\lambda)-\mu]^2}{2\sigma^2}\right\} dx \quad (2)$$

using previously defined parameters.

The relation between the CDF (i.e., *F(x)*) and the recurrence interval (*T*) used in flood hydrology is given by the equation:

$$F(x) = 1 - \frac{1}{T} \tag{3}$$

where $F(x)$ is the CDF and T is the recurrence interval in years.

A common practice in flood hydrology is to express floods using an index of floods. Results of the index of floods were also reported within this study. This approach permits the estimation of higher return floods using data from lower return floods (e.g., estimation of 5-year flood from data on the 2-year flood). In the present study, flood flows were expressed as QFT where T represents the recurrence interval (i.e., QF2 is a 2-year flood). The index of floods consists of calculating the mean ratio of higher return floods to low return floods within a given region (e.g., QF5/QF2). For the calculations of the index of floods within the Maritime Provinces, both the QF2 (2-year flood) and QMF (Mean Annual Flood) were used as the index. The ratio of QFT/QF2 is the most commonly use index of flood in hydrology; however, we have chosen to also include the ratio of QFT/QMF within this study, because the QMF can be more easily calculated. In fact, the QMF is obtained by simply averaging the annual floods whereas the QF2 is obtained through the fitting of a distribution function.

For low flow frequency analysis, the 3-parameter Weibull distribution function was used. The probability density function (PDF) of the Weibull distribution is given by:

$$f(x) = \frac{\beta}{\alpha^{\beta}}(x - \lambda')^{\beta-1} \exp\left\{-\left(\frac{x - \lambda'}{\alpha}\right)^{\beta}\right\} \tag{4}$$

where, α is the scale parameter and $\beta > 0$ is a shape parameter and λ' is the threshold parameter for low flows.

The cumulative distribution function (CDF) of the 3-parameter Weibull distribution function is given by the following equation:

$$F(x) = 1 - \exp\left\{-\left(\frac{x-\lambda'}{\alpha}\right)^{\beta}\right\} \tag{5}$$

where parameters are the same as in equation (4)

The relation between the CDF (i.e., *F(x)*) and the recurrence interval (*T*) for low flows is given by:

$$F(x) = \frac{1}{T} \tag{6}$$

In the present study, low flows were expressed as QLT where T represents the recurrence interval (i.e., QL5 represents a 5-year low flow event).

2.4 Regional regression equations

Characteristics of floods and low flows differ from one drainage basin to another and results of single station analysis are only applicable to the specific gauged streams or those streams near hydrometric stations. As many water resource projects are undertaken within ungauged basins, there is a requirement for the development of regional equations (e.g., mean flows, flood and low flow estimates).

Regional regression analysis consists of establishing a relationship between flow metrics (mean flows, high and low flows, etc) and physiographic parameters describing the basin. With the discharge as the dependent variable and the physiographic factors as the independent variable (in this case, drainage area), a linear regression was performed using log-transformed data to evaluate the parameters of the following equation:

$$Q_T = a\, DA^b \tag{7}$$

where, a and b are regression constant, DA is the drainage area (km^2) and Q represents the flow (mean annual flow, flood or low flow for different recurrence interval in m^3/s). In the present study, the regression parameters a and b were calculated using the regression function in Excel (MICROSOFT EXCEL™ 2002).

3.0 RESULTS AND DISCUSSION

Within the Maritimes Provinces, 55 hydrometric stations were analysed using data from the Environment Canada HYDAT database (Environment Canada, 2003). The site location (latitude and longitude), station ID and years of record used are presented in Table 1. The location of each hydrometric station throughout the Maritime Provinces is shown in Figure 2. All stations had more than 20 years of data with the exception of three hydrometric stations (Catamaran Brook, NB, West River, PEI and Bear River, PEI). Although these stations had fewer than 20 years of data, they were kept part of the analysis in order to increase the number of small basins within the study. Long-term average precipitation and air temperatures are presented for selected sites within the Maritime Provinces in Figure 3. This figure shows that the warmest sites within the studied region were observed in the southwestern part of NS with mean

annual air temperatures reaching 7.0 °C. The coldest temperatures were in the northern NB at 3.2 °C. Precipitation also showed a slight north - south gradient, particularly in NB with values of 1100 mm in the north and 1400 mm in the south. PEI receives approximately 1100 mm of precipitation annually whereas precipitation in NS varies between 1200 mm and 1500 mm. The highest precipitation in NS was observed in Cape Breton.

3.1 Mean Annual Flow

The drainage basin area of the studied hydrometric stations in the Maritime Provinces varied between 10.1 km^2 (Fraser Brook, NS) and 14 700 km^2 (Saint John River, NB), and with a correspondingly large range in the mean annual flow (MAF, 0.239 m^3/s and 272 m^3/s; Table 2). Notably, the mean annual flow by provinces varied between 0.536 m^3/s (Middle Branch Nashwaaksis Stream, 26.9 km^2) and 272 m^3/s (Saint John R., 14 700 km^2) in NB, between 0.239 m^3/s (Fraser Brook, 10.1 km^2) and 42.9 m^3/s (St. Marys R., 1350 km^2) in NS and between 0.32 m^3/s (Bear R., 14.8 km^2) and 2.54 m^3/s (Dunk R., 114 km^2) in PEI. Figure 4 shows the relation between the MAF and the drainage area (*DA*) for all stations within the three Maritime Provinces. Regression equations are provided in Table 3. A good agreement between the regression lines and observed data was observed throughout the study region, with over 95% of the variability explained. NB and PEI regression lines provided similar flows whereas the regression equation for NS showed slightly higher MAFs for similar drainage basin (Figure 4). It is worth noting that the three data points which showed a greatest departure form the regression line in NS were all Cape Breton rivers. Therefore, this shows that Cape Breton rivers can experience slightly higher mean annual flows per drainage basin area compared to the Mainland NS rivers. Regression lines showed exponents very close to unity, i.e., b = 0.980 (NB), 0.961 (NS) and 1.050 (PEI). This means that small and large rivers behave similarly to precipitation and that the relationship is almost linear. Also noted was the fact that all regression lines

showed a high coefficient of determination with R^2 of 0.949 (NS), 0.980 (PEI) and 0.986 (NB).

Also reported in Figure 4 is the MAF per drainage area (expressed as L/s per km^2) for drainage basins of 10 km^2, 100 km^2 and 1000 km^2 by province. Because of the similarities in MAF for a wide range of drainage basins, such flows per unit drainage area can be use in the estimation of water availability without introducing too many errors. Results from the regression equations showed that the MAF in both NB and PEI were very close and at approximately 22 L/s/km^2. As for NS, rivers experienced slightly higher MAFs by more than 10 L/s/km^2. Values were in the range of 32 L/s/km^2 to 38 L/s/km^2 depending on basin size and where smaller basins generally experienced slightly higher flows. This comparison of MAFs revealed that flows in NS were 50-60% higher than those in NB and PEI despite the fact that the precipitation in NS was only 30% higher than NB and PEI. These relatively higher MAFs for NS are likely the result of a combination of factors such as higher precipitation, topography and geology, which all impact on the runoff coefficient (or the percentage of precipitated water reaching rivers). For instance, higher MAFs were recorded in the Highlands of Cape Breton presumably as a result of a combination of higher precipitation and gradient. The MAF per drainage area for each station is also presented in Table 2. The average MAF per drainage area calculated from Table 2 was 22.1 L/s/km^2 for NB, 35.1 L/s/km^2 for NS and 20.0 L/s/km^2 for PEI. These values were very comparable to values calculated from the regression equations (Figure 4). In terms of spatial distribution, Table 2 shows consistent MAFs per drainage area throughout NB and PEI, with the exception of a few stations in southern NB which showed higher than average flows, i.e., Lepreau R. (30.6 L/s/km^2) and Point Wolfe R. (38.9 L/s/km^2). These higher flows are most likely due to the higher precipitation and the steeper terrain experienced in the southern part of the province. In NS, flows (expressed as MAF/DA) were higher than both NB and PEI and there was a clear difference in flows between rivers of the Mainland NS and those located within Cape Breton. For example, Mainland NS

showed mean flows of 29.8 L/s/km^2 whereas mean flows were much higher in Cape Breton at 46.9 L/s/km^2. In Cape Breton, mean flows for both the Cheticamp River (57.4 L/s/km^2) and Indian Brook (79.4 L/s/km^2) showed significantly higher values than other rivers. These within province differences can be mostly attributed to the higher precipitation experienced in the western part of the province (e.g., Cape Breton) relative to those in the eastern section, as well as the differences in topography.

3.2 Flow duration analysis

A flow duration analysis was also carried out for each gauged river within the Maritimes Provinces. The flow duration analysis provides information on the percentage of the time that flows are equalled or exceeded, such as flows that correspond to 50% and 90% of the time (i.e., Q_{50} and Q_{90}). The median flow (Q_{50}) varied from 0.23 m^3/s to 132.5 m^3/s for NB, from 0.13 m^3/s to 26.7 m^3/s for NS and from 0.21 m^3/s to 1.76 m^3/s for PEI (Table 2). Previous studies have showed that the Q_{50} generally corresponds to approximately half of the mean annual flow (Leopold 1994, Caissie 2006b). For NB, the median flows varied between 27% (Bass R.) and 56% (Lepreau R.) of the MAF, with an average of 47% of the MAF. Therefore, in NB median flows (Q_{50}) were approximately 50% of the MAF on average. In NS, Q_{50} represented a slightly higher percentage of the MAF and ranged from 47% (River John) to 94% of MAF (Southwest Margaree R.). The mean value for NS was 62% of MAF. It was nevertheless noted that larger systems in NS (> 250 km^2) had a Q_{50} that corresponded to a slightly higher mean value at 69% whereas small basins (< 250 km^2) showed a mean percentage closer to 55% of the MAF. In PEI, the Q_{50} represented between 51% (Carruthers Brook) and 71% (West River) of MAF with a mean percentage of 66% of MAF, a percentage higher than NB and NS. The Q_{50}, representing different percentage of MAF by station and provinces, is reflective of a slightly different distribution of flows. The greater the difference between the median and the mean (i.e., Q_{50} representing a lower percentage of MAF) indicates a more highly skewed (positively) flow distribution.

Similar to the MAF, regression equations can be calculated between the Q_{50} and drainage area (*DA*). Results showed a good relationship between the Q_{50} and drainage area (Figure 5) with R^2 ranging between 0.95 and 0.96, although these coefficients of determination were slightly lower than those for the MAF (Table 3). Results also confirmed that the Q_{50} were generally 50% of the MAF in NB, with values close to 10 L/s/km^2 for a wide range of basins (between 10 and 1000 km^2; Figure 5). In PEI values were between 11.8 L/s/km^2 and 14.4 L/s/km^2. In NS, Q_{50} were generally higher, between 18 5 L/s/km^2 and 21.5 L/s/km^2, and these flows corresponded to values closer to 60% of MAF based on the regression analysis. In describing the hydrologic character of rivers, both the MAF and Q_{50} are important in the estimation of the water availability and these metrics are also key in most instream flow studies.

The Q_{90}, representing low flows, was also calculated for each station by province (Table 2). Values of Q_{90} varied between 0.035 m^3/s and 44.4 m^3/s in NB, between 0.017 m^3/s and 4.26 m^3/s in NS and 0.073 m^3/s and 0.969 m^3/s in PEI. As was the case for the MAF, the Q_{90} were slightly lower in NB compared to those for similar size basins in NS. In contrast, Q_{90} in PEI showed the highest values of all three provinces for similar size basins, mainly due to the fact that PEI rivers generally experience more baseflow and groundwater contributions. Similar to the Q_{50}, a comparison was carried out between the Q_{90} and the MAF. Notably, the Q_{90} is a low flow value that represents on average approximately 14% of the MAF in NB, 12% of the MAF in NS and 30% of the MAF in PEI. This means that low flows are more severe in NS than in NB whereas PEI rivers clearly experience a significant amount of baseflow at 30% of MAF. Baseflow indices are often used to estimate the relative contribution of groundwater or baseflow. Such an index of baseflow was calculated using the ratio of Q_{90}/Q_{50}. A higher baseflow index is also reflective of a flatter flow duration curve. Calculated ratio of Q_{90}/Q_{50} are presented in Table 2. Baseflow index (Q_{90}/Q_{50}) values ranged between 0.135 and 0.403 in NB, 0.075 and 0.416 in NS and

0.351 and 0.559 in PEI. Mean values by province were 0.285 (NB), 0.188 (NS) and 0.455 (PEI). These results clearly show significantly higher baseflow contributions for PEI rivers as well as the more severe low flows experienced in other provinces, particularly in NS. When looking at the relationship between the baseflow index and drainage area (excluding PEI rivers because the range of basin sizes was too small and the baseflow behaviour was clearly different), it was noted that smaller baseflow index generally corresponded to smaller basin and vice versa. For example, small basins (< 100 km^2) generally experiences a baseflow index less than 0.25 whereas large rivers (> 1300 km^2) generally showed a baseflow index higher than 0.30 (Table 2). As for mid-size basins (100 km^2 < *DA* < 1300 km^2), they generally showed more transitional results.

A regional flow duration curve was calculated for each province, as shown in Figure 6, with flows expressed as discharge per unit area (L/s per km^2). This figure shows flows corresponding to different percentage (from 0% to 100%) on the flow duration curve, as well as flow variability using a box plot representation (Figure 6a, 6b and 6c). Figure 6d compares the flow duration results among the different provinces without the box plots. From Figure 6a to 6c, it can be observed that flows at 10% showed among the lowest variability (all provinces). The flow variability increased for lower flows, particularly for percentages higher than 80% (Q_{80}). The box plots showed that NS rivers had the highest variability at low flows (0.01-1 L/s/km^2 at Q_{100}; Figure 6b). When comparing regional flow duration curves among provinces (Figure 6d), NS showed generally higher flows than in NB and PEI for flows less than 70%; however, NS also experienced lower low flows particularly for flows exceeding 70% for PEI and for flow exceeding 90% for NB. These results showed that most flows (MAF and Q_{50}) were generally higher in NS and that low flows were also more severe in NS. PEI clearly experienced a flatter regional flow duration curve, and indicative of a relatively high baseflow contribution, as was previously shown from the baseflow index.

3.3 Mean Monthly Flow

The above flow characteristics provided mainly spatial data for the studied region. In order to study the temporal characteristics of flow (e.g., within the year), the mean monthly flow for each hydrometric station was used. Figure 7 shows results of mean monthly flows divided by the mean annual flow for each month and station. The highest flow month generally occurred in April or May whereas the lowest flow month occurred most often during the month of July, August or September. In northern NB, some stations showed the lowest monthly flow during the winter period, mainly form January to February. Results showed that peak monthly flows in NB were significantly higher than those in NS and PEI. In fact, peak monthly flows in NB averaged 3.1 (or 310% of the MAF) for rivers that peaked in April and 3.6 (or 360% of MAF) for rivers that peaked in May. Rivers that peaked in May were generally in the northern part of the provinces. This timing of the high flows in May is related to lower winter air temperatures and more precipitation in the form of snow in winter. For example, Meduxnekeag R. (3.7; 01AJ003; Figure 7a) had the maximum value among rivers that peaked in April whereas Jacquet R. (4.3; 01BJ003; Figure 7c) had the maximum values among those that peaked in May. Most rivers in NS peaked in April with an average value at 2.1 (or 210% of MAF), i.e., much lower than for NB rivers. Five rivers in NS peaked in May and they were all at the northern tip of the Cape Breton Island (average of 2.4). PEI rivers showed peak monthly flows in April with a mean value of 2.2, with the exception of Carruthers Brook (01CA003) which peaked at 3.3 (330% of MAF). PEI rivers also showed the more stable flow regime compared to NB and NS.

Summer monthly low flows generally occurred between August and September in NB and PEI, whereas low monthly flows generally occurred earlier in NS (i.e., July and August). For NB, August (0.4 or 40% of MAF) and September (0.38 or 38% of MAF) average values were very similar (Figure 7). Low monthly flows were more severe in NS with a mean value of 0.34 (for both July and August). PEI summer low flows were slightly higher than NB with an average value of 0.43 (for both August and

September). Winter low monthly flows occurred in February in all provinces and they were more severe in NB (0.47) compared to NS (0.94) and PEI (0.89). These more severe low monthly flows in NB were linked to the lower winter air temperature within the province. It is worth noting that winter low flows in NB were as severe as those experienced during the summer months which was not the case for other provinces.

3.4 Timing of high and low flows

A high and low flow frequency analysis was carried out for all 55 hydrometric stations across the Maritime Provinces. However, before this analysis, the time of occurrence of minimum and maximum daily discharge (by month) was extracted from the HYDAT database and values were analysed. The occurrence of low and peak flows varied between season and provinces (Figure 8). This figure shows the proportion of low flows and peak flows for each month by provinces. For instance, peak flows occurred mainly from March to May within the Maritime Provinces. In NB, the greatest occurrence of high flows was observed during the month of April with a frequency of 42% followed by May at 30% (Figure 8). In NS, peak flows were more evenly distributed throughout the year; however peak flows occurred more frequently during the winter and autumn months (with the highest occurrence in April at 22%). PEI rivers experienced a high portion of peak flows in April (37%) and May (32%) with a few events in autumn; however, peak flows were never observed during the summer months (June-August). Results showed that autumn peak flows were more prevalent in NS than in NB and PEI. The high frequency of flood events during the spring in NB (compared to other provinces) is most likely related to the dominant spring snowmelt conditions within this province; whereas NS experienced more distributed winter high flows due to a milder winter climate.

The occurrence of low flows within the Maritime Provinces was mainly observed in late summer (August and September) although low flows were also possible in winter, especially in NB and to some extent in PEI (Figure 8). For instance,

most low flows occurred in September (31%) in NB and to a lesser extent during other summer and autumn months (July, August and October, 10-15%). In this province, a significant portion of low flows occurred from January to March with most occurrences in March (15%). In NS, very few low flows were observed in winter whereas most occurred in July to October and with a maximum occurrence in August (34.3%) and September (33.7%). These results show that low flows in NS occur sooner than in NB and PEI. Low flows in PEI were observed both in winter and summer. Low flows in winter were most prevalent in January (10%) whereas summer low flows occurred mostly in September (33%).

3.5 High flow frequency

After calculating the timing of high and low flows within the year, the magnitude of the events were studied using a frequency analysis. The distribution function used for the high flow analysis was the 3-parameter lognormal for all stations, as it was found to represent peak flows well in previous studies (Environment Canada and New Brunswick Department of Municipal Affairs and Environment, 1987). The Gumbel (Type 1 Extremal) distribution function was also tested for a few stations where the 3-parameter lognormal did not provide as good a fit as with other stations; however, the Gumbel distribution did not significantly improve the fitting. Each data point that represented the maximum annual daily discharge in relation to its cumulative frequency (f) was plotted graphically using the Weibull plotting position formula (Chow et al. 1988):

$$f = \frac{m}{n+1} \tag{8}$$

where m refers to the rank of the annual maximum daily discharge in increasing order, and n is the number of years of record. Given the cumulative frequency (f), the position on the x axis is determined using the Gumbel reduced variable y':

$$y' = -\ln(-\ln(f)) \tag{9}$$

where f is the cumulative frequency calculated by equation (8). The above transformation was used for plotting high and low flow data due to the logarithmic nature of these events. This type of a plotting transformation is referred to as plotting data on a Gumbel paper.

Most data followed well the fitted 3-parameter lognormal distribution with the exception of a few stations (Figure 9). This figure shows typical examples of the observed fit for the studied provinces. For example, data for Canaan R. (NB; Figure 9a), Jacquet R. (NB; Figure 9b) and Wilmot R. (PEI; Figure 9e) are typical examples of a good fit of the 3-parameter lognormal distribution. In contrast, data for Indian Brook (NS; Figure 9c), Musquodoboit R. (NS; Figure 9d) and Carruthers Brook (PEI; Figure 9f) show examples where data did not fit as well the distribution function, particularly at high flows. For cases such as Indian Brook, the application of the Gumbel distribution function did not significantly improve the fit and therefore high flow frequencies were estimated using the 3-parameter lognormal distribution function for all sites.

Results of the single station high flow frequency analysis are provided in Table 4 for recurrence intervals of 2, 5, 10, 20, 50 and 100 years, as well as for the mean annual flood (QMF). High flows within the Maritime Provinces are reflective of basin sizes with the Saint John River (NB) showing the highest 2-year floods (2317 m^3/s) and Fraser Brook (NS) showing the lowest value (2.3 m^3/s). After the single station analysis, regional regression equations were then calculated to study the relation between high flows and basin sizes, in order to estimate high flows for ungauged basins. Regional regression equations are presented in Table 5. Coefficients of

determination (R^2) were significantly higher in NB (0.942 to 0.977) than in NS (0.763 to 0.839). PEI values were similar to those in NB for low return floods (e.g., T=2) and slightly lower for higher return flows (e.g., T=50). It should be noted that these regression equations were developed for a specific range of basin sizes and should not be applied outside these ranges (Table 5). For examples, equations in PEI were developed for basin ranging between 14.8 km^2 and 114 km^2. The relationship between floods of different recurrence intervals is presented in Figure 10 (for QMF, QF2, QF10 and QF50). This figure shows a good relation between high flows and drainage area, particularly in NB and NS, although NS rivers showed higher variability (reflected by lower R^2). This higher variability in NS was mainly due to the fact that some rivers, particularly in Cape Breton, had slightly higher flows. For example, the higher data points (for three stations in NS, Figure 10a and 10b) were all Cape Breton rivers. PEI rivers showed relatively lower flows for smaller size rivers, which resulted in a steeper slope of the regression line.

The mean annual flood (QMF) has a particular interest in hydrological and instream flow studies because it represents a low return flood and it can be used as a surrogate for the 2-year flood which often used as the bankfull discharge or channel forming flow. In fact, studies have shown that both the mean annual flood and the 2-year flood (QF2) are very close to the bankfull discharge and therefore both these flows can be used to represent the bankfull discharge in rivers (e.g., Leopold 1994; Caissie 2006b). For instream flow studies, these low return floods are important to maintain the character of rivers (e.g., channel form) as well as flushing fines to maintain a good substrate composition. The use of the QMF to represent low return floods provides an advantage, particularly in terms of its simplicity in calculation. For instance, the QMF showed a very close association to the 2-year floods although the QMFs were slightly higher (Figure 11). In fact, the QMFs were higher than the QF2 on average by 9.4 % in NB, 11.3% in NS and by 11.0% in PEI.

3.6 Index flood approach

Another approach used to calculate flood flows when low return floods are known (e.g., QF2 and/or QMF) is the index flood approach. This approach has the advantage in both hydrologic and instream flow studies of being able to calculate floods of different recurrence intervals without necessarily carrying out a frequency analysis. Flood indices are calculated based on the ratio of high return floods to low return floods, e.g., the 2-year flood flow event or the mean annual flood as the index. Table 6 shows results of the index flood approach within the Maritime Provinces using the 2-year flood as the index. In NB, the index of flood was calculated at 1.4, 1.7, 1.9, 2.3 and 2.7 for a 5, 10, 20, 50 and 100-year flood event. The index of floods was presented for other provinces and results were very similar to those in NB, especially for low return floods. A slight difference in the indices was noted at higher return floods (such as the QF100/QF2) where indices were 2.7 (NB), 2.8 (NS) and 2.9 (PEI). Also shown in this table is the coefficient of variation (*Cv*) expressed in percentage, which indicates the variability of each index by provinces. The coefficients of variation were slightly lower in NB followed by NS and PEI. This shows that there is more similarly among stations in NB than for other provinces. The variability also increased with increasing recurrence intervals and in the range of 5.8%-7.7% for QF5/QF2 whereas the variability increased to 26%-31% for QF100/QF2. Higher flood indices were generally observed for smaller basins whereas lower values were observed for larger rivers. This is indicative of the slope of the flood curve, where a higher index (or ratio) represents a more responsive drainage basin to flooding, which is more prevalent for small basins.

In the application of the index flood approach, the 2-year flood is most often used in the literature. However, the 2-year flood has to be estimated, either by using the single station analysis (with a distribution function such as the 3-parameter lognormal distribution function) or by using regional regression equations (regression equation for the 2-year flood; Table 5). There are cases where it would be an advantage to use the mean annual flood (QMF) rather than the 2-year flood (because the calculations to

obtain the QMFs are simpler). Results of the index flood approach using the QMF (rather than the QF2) are given in Table 7. Because the QMFs are on average approximately 10% higher than the 2-year floods, indices were slightly lower. Notably, the indices were calculated at 1.3, 1.5, 1.8, 2.1 and 2.4 for NB rivers for recurrence intervals of 5, 10, 20, 50 and 100 years, respectively. Similar indices were calculated for other provinces (Table 7). It was also noted that the coefficients of variation were slightly lower (i.e., 2% to 25%) when using the mean annual flood as the index (Table 7) compared to results when using the 2-year flood as the index (Table 6). Overall, the index flood approach show that a 100-year flood is approximately 2.5 times the QMF or 2.8 times the QF2.

For drainage basins where the mean annual flow (MAF) is available but with few or no data on floods, comparison can be made between the ratio of the 2-year flood (QF2) and the mean annual flow using the regression equations (Table 3 and Table 5; Caissie 2006b). Results revealed that the ratio of the QF2/MAF was approximately 9 within the Maritime Provinces and generally varied between 6 and 12 depending on drainage size and province. Therefore, as a general rule of thumb, where data are available for the MAF with no data on floods, the QF2 can be approximated to be 9-10 times the MAF. Such results should always be corroborated with regional equations as well.

3.7 Low flow frequency

A low flow frequency was also carried out for Maritimes Province rivers. For the low flow analysis, the annual daily discharge was extracted from the HYDAT database. Then these data were fitted to a low flow frequency distribution function and plotted graphically on a Gumbel paper using the Weibull plotting position (similar to flood data). The distribution used for the analysis of low flows was the Type 3 Extremal distribution function (also known as the 3-parameter Weibull distribution

function). Figure 12 shows typical fit of the low flow distribution function for different stations across the Maritime Provinces. Notably, some stations can provide a zero flow, as was the case for North Branch Oromocto River (station 01AM001; Figure 12a) and the Winter River (station 01CC002; Figure 12f); however, the prediction of zero flows was the exception rather than the norm within the study region. In fact, most stations showed non-zero low flows and the 3-parameter Weibull distribution function provided a very good fit for the low flow time series (Figure 12). Table 8 shows the results of the 2, 5, 10, 20 and 50-year low flows for all stations. The QML represents the average minimum annual discharge. This flow statistic was obtained by averaging annual minimum low flows. Similar to the high flow situation, the QML and the 2-year low flow (QL2) were very closely related; however, the QML was on average 14% higher than the QL2. The relationship between QML and QL2 is shown in Figure 13.

Results of the regional low flow analysis are shown in Table 9. Due to extremely low water conditions, four stations out of 55 were excluded from the regression analysis. These stations were: North Branch Oromocto River (NB), Beaverbank River (NS), Fraser Brook (NS) and Gold River (NS). Low flows for these rivers were either zero flows or too low to be included within the regression equations without influencing the overall results (i.e., stations considered as outliers). These results show that most rivers had similar low flow behaviour; however, some rivers experienced very low water conditions. This was especially the case for some small rivers and users should be aware of these differences in low flows. The Clam Harbour River was excluded for the 50-year regression equation only (reducing the number to 22) due to the zero flows at QL50 (Table 9). Regression equations showed coefficients of determination (R^2) ranging from 0.899 to 0.945 in NB, from 0.554 to 0.791 in NS and from 0.375 to 0.857 in PEI. It was noted that the regression equations for low flows generally explained less of the variability compared to floods. Also, higher return low flows (e.g., QL20 and QL50) showed more uncertainties, with coefficients of determination (R^2) ranging from 0.375 (PEI, QL50) to 0.909 (NB, QL20). Regression

equations in NB showed the best overall fit, although the regression equations for both NB and NS were very similar (Figure 14). In contrast, PEI regression equations showed much higher low flows than in both NB and NS for similar size basins. Also noted from Table 9 was the fact that the exponent *b* was higher than one (from 1.2 to 1.4). This indicates that larger rivers will experience correspondingly higher low flows per drainage area (i.e., less severe low flows) compared to small basins. As an example, a QL2 low flow of 0.92 L/s per km^2 was calculated in NB for a basin of 30 km^2 whereas a discharge of 1.51 L/s per km^2 for a basin of 300 km^2. Likewise a QL2 of 2.48 L/s per km^2 was calculated for a basin of 3000 km^2. These results clearly show the predominance of more severe low flows among the smaller basins.

4.0 SUMMARY AND CONCLUSIONS

River hydrology plays a key role in instream flow evaluation where different components of flows need to be clearly understood before any water withdrawal. The objective of the present study was to provide detailed hydrological information on Maritime Rivers. More specifically, information was provided on flow availability (annual and monthly flow characteristics and flow duration), on the frequency of low flows and high flows (and index of floods) as well as on the timing of these events. Such information and data will ultimately help in the instream flow assessment process as well as during environmental impact assessment of water removal or water course alteration projects.

Water availability within the Maritime Provinces was somewhat consistent except for NS where MAF were almost 50% higher than in NB and PEI for similar basin size. Even higher water availability was noted for Cape Breton rivers. These differences were mainly due to the higher amount of precipitation in NS, especially in Cape Breton. The groundwater contribution in PEI rivers was also noted to be higher which was both reflected in the flow duration curve and the low flow characteristics.

Low flows were not as severe in PEI when compared to NB and NS values. These different characteristics have profound implications for aquatic habitats within these provinces. Although low flows were similar in magnitude among NB and NS, the province of NS experienced the most severe low flows as a percentage of their MAF because of higher water availability. This has potential implications on the degradation of aquatic habitat during low water periods. In fact, because NS rivers naturally experience more severe low water conditions in summer, fish habitat within these rivers will more likely be degraded or dewatered (especially in riffles) than in other provinces. In contrast, winter low flow conditions are not as severe in NS and PEI as they are in NB. This means that overwinter survival related to low flow conditions is more of a concern in this province.

Mean monthly flows (MMF) were also calculated in this study and data were presented as a ratio (or percentage) to the mean annual flow. It was observed that the MMFs were generally higher in April and May for all the Maritimes rivers. MMF averaged between 3.1 (April) and 3.6 (May) of MAF in NB whereas NS and PEI experienced considerably lower values (2.1-2.4 of MAF). It was noted that all rivers in NS and PEI peaked in April (2.1-2.4 of MAF) whereas rivers in Cape Breton peaked in May (2.4 of MAF). The lowest flow months generally occurred in late summer (August and September) with values close to 0.4 of MAF. NS rivers generally experienced more severe summer low flows (0.34 of MAF) and their low MMFs occurred one month earlier (July and August). NB was the only province that experienced winter low MMFs with an average values 0.47 of MAF in February.

Regional equations were developed for a variety of flows as a function of the drainage area. Results showed that the MAF and Q_{50} equations explained most of the variability followed by floods and low flows. Differences among provinces were noted in the MAF, Q_{50} and low flow equations whereas the flood equations showed the most similarities among provinces. Cape Breton rivers showed different hydrologic

behaviour at all levels (mean, high and low flows). Two new flow metrics were presented within the present study, namely the mean annual flood (QMF) and the average minimum annual discharge (QML), which are not commonly used in hydrological studies. The advantage of these flow metrics are that they reflect on the magnitude of low return floods and low return low flows without necessarily having to carry out the more elaborate frequency analysis. Also, combined with the index of flood approach, users can determine different flood flows effectively using very simple analysis.

In conclusion, we believed that such a regional characterization of river hydrology will help both water resource and fisheries managers to better deal with water issues (e.g., water availability and instream flow requirements). Such characteristics provide a better overall picture of the natural flow regime of rivers within the Maritime Provinces and will ultimately contribute to better hydrological and instream flow studies. Similarities in river hydrology were observed; however, many differences were also pointed out, particularly in water availability in NS, groundwater contributions in PEI, winter droughts in NB and the distinct nature of Cape Breton rivers. Differences were also observed between small and large river systems both in flood and low flow hydrology. Equations and indices provided will help both hydrologists and biologists to relatively simply and quickly assess water resource projects. However, depending on the magnitude and nature of the problem or issues, more detailed analyses may be required.

5.0 ACKNOWLEGEMENTS

This study was partially funded by NSERC and CHIF (the Centre of Expertise on Hydropower Impacts on Fish and Fish Habitat) and their support was greatly appreciated. We also thank the following people for their contribution within the present study: Patrick Miller for carrying some of the calculations, Peter Hardie and Dr. Loubna Benyahya for reviewing the manuscript.

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Table 1. Analysed hydrometric stations within the Maritime Provinces.

River	Station ID	Latitude	Longitude	Period	Number of years
			New Brunswick		
Saint John River	01AD002	47°15'25"N	68°35'35"W	1951-2003	52
St. Francis River	01AD003	47°12'25"N	68°57'25"W	1952-2003	52
Limestone Stream	01AG002	46°49'42"N	67°44'35"W	1968-1993	26
Meduxnekeag River	01AJ003	46°12'58"N	67°43'42"W	1968-2003	36
Shogomoc Stream	01AK001	45°56'42"N	67°19'20"W	1951-2003	53
Middle Branch Nashwaaksis Stream	01AK005	46°02'06"N	66°42'05"W	1966-1993	28
Nashwaak River	01AL002	46°07'33"N	66°36'44"W	1962-2003	42
North Branch Oromocto River	01AM001	45°40'25"N	66°40'58"W	1963-2003	41
Canaan River	01AP002	46°04'19"N	65°22'00"W	1663-2003	41
Kennebecasis River	01AP004	45°42'07"N	65°36'05"W	1962-2003	42
Lepreau River	01AQ001	45°10'12"N	66°28'00"W	1951-2003	53
Restigouche River	01BC001	47°40'00"N	67°29'03"W	1963-2003	41
Upsalquitch River	01BE001	47°49'54"N	66°52'54"W	1951-2003	53
Tetagouche River	01BJ001	47°39'21"N	65°41'37"W	1952-1994	43
Jacquet River	01BJ003	47°53'52"N	66°01'47"W	1965-2003	39
Bass River	01BL001	47°39'00"N	65°34'40"W	1966-1990	25
Southwest Miramichi River	01BO001	46°44'10"N	65°49'36"W	1962-2003	42
Renous River	01BO002	46°49'17"N	66°06'53"W	1966-1994	29
Little Southwest Miramichi River	01BP001	46°56'09"N	65°54'26"W	1952-2003	52
Catamaran Brook	01BP002	46°51'27"N	66°11'18"W	1990-2003	14
Northwest Miramichi River	01BQ001	47°05'41"N	65°50'14"W	1962-2003	42
Coal Branch River	01BS001	46°26'37"N	65°03'55"W	1965-2003	39
Point Wolfe River	01BV006	45°33'32"N	65°01'02"W	1965-2003	39
			Nova Scotia		
Annapolis River (Wilmot)	01DC005	44°56'59"N	65°01'47"W	1964-2003	40
Annapolis River (Lawrencetown)	01DC007	44°52'02"N	65°09'58"W	1984-2003	20
Beaverbank River	01DG003	44°51'06"N	63°39'54"W	1955-2003	49
Fraser Brook	01DH003	45°20'35"N	63°10'05"W	1966-1990	25
Kelley River(Mill Creek)	01DL001	45°35'10"N	64°27'05"W	1970-2003	32
Wallace River	01DN004	45°40'42"N	63°33'35"W	1965-1998	34
River John	01DO001	45°43'42"N	63°03'09"W	1966-1994	29
Middle River of Pictou	01DP004	45°29'50"N	62°46'51"W	1966-2003	36
South River	01DR001	45°33'35"N	61°54'15"W	1966-2003	38
Roseway River	01EC001	43°50'18"N	65°22'12"W	1950-2003	54
Mersey River	01ED007	44°26'14"N	65°13'24"W	1969-2003	35
LaHave River	01EF001	44°26'48"N	64°35'30"W	1950-2003	54
Gold River	01EG002	44°33'52"N	64°21'06"W	1966-1996	31
Sackville River	01EJ001	44°43'53"N	63°39'45"W	1971-2003	33
Musquodoboit	01EK001	44°52'18"N	63°13'18"W	1950-1994	45
Liscomb	01EN002	45°00'54"N	62°05'45"W	1963-1995	33
St. Marys River	01EO001	45°10'24"N	61°58'54"W	1950-2003	54
Clam Harbour River	01ER001	45°28'06"N	61°27'36"W	1959-1994	36
River Inhabitants	01FA001	45°43'15"N	61°17'10"W	1966-2003	38
Northeast Margaree	01FB001	46°22'10"N	60°58'36"W	1950-2003	54
Southwest Margaree River	01FB003	46°13'24"N	61°08'12"W	1950-2003	54
Cheticamp River	01FC002	46°38'28"N	60°56'49"W	1959-2000	42
Wreck Cove Brook	01FD001	46°31'23"N	60°25'20"W	1957-1976	20
Indian Brook	01FE002	46°22'15"N	60°32'05"W	1961-2003	41
Grand River	01FH001	45°43'48"N	60°36'12"W	1950-1994	45
Macaskills Brook	01FJ002	46°06'59"N	60°00'26"W	1979-2003	25
			Prince Edward Island		
Carruthers Brook	01CA003	46°44'39"N	64°11'08"W	1962-2003	42
Dunk River	01CB002	46°20'45"N	63°38'03"W	1962-2003	42
Wilmot River	01CB004	46°23'35"N	63°39'35"W	1972-2003	32
Winter River	01CC002	46°19'56"N	63°03'53"W	1968-2003	36
West River	01CC005	46°13'50"N	63°21'07"W	1989-2003	15
Bear River	01CD005	46°27'11"N	62°22'56"W	1995-2003	9

Table 2. River discharge, drainage area and flow duration calculations for analysed hydrometric stations within the Maritime Provinces.

River	DA (km^2)	MAF (m^3/s)	MAF/DA ($L/s/km^2$)	Q_{50} (m^3/s)	Q_{90} (m^3/s)	Q_{90}/Q_{50}
New Brunswick						
Saint John River	14700	272	18.5	132.5	44.40	0.335
St. Francis River	1350	24.7	18.3	11.95	4.212	0.353
Limestone Stream	199	3.65	18.3	1.834	0.663	0.362
Meduxnekeag River	1210	24.6	20.3	10.65	2.547	0.239
Shogomoc Stream	234	4.95	21.2	2.543	0.536	0.211
Middle Branch Nashwaaksis Stream	26.9	0.536	19.9	0.234	0.035	0.150
Nashwaak River	1450	34.9	24.1	17.68	5.832	0.330
North Branch Oromocto River	557	12.0	21.5	5.782	0.783	0.135
Canaan River	668	13.2	19.8	5.734	0.855	0.149
Kennebecasis River	1100	25.0	22.7	13.55	3.490	0.258
Lepreau River	239	7.32	30.6	4.346	0.977	0.225
Restigouche River	3160	66.1	20.9	32.91	12.16	0.369
Upsalquitch River	2270	40.6	17.9	18.23	7.153	0.392
Tetagouche River	363	7.67	21.1	3.04	0.913	0.300
Jacquet River	510	10.2	20.0	3.726	1.265	0.340
Bass River	175	3.16	18.1	0.855	0.169	0.198
Southwest Miramichi River	5050	116	23.0	62.06	25.34	0.408
Renous River	611	14.6	23.9	6.952	2.348	0.338
Little Southwest Miramichi River	1340	32.2	24.0	16.75	6.759	0.403
Catamaran Brook	28.7	0.596	20.8	0.278	0.070	0.252
Northwest Miramichi River	948	20.9	22.0	9.661	3.527	0.365
Coal Branch River	166	3.63	21.9	1.476	0.319	0.216
Point Wolfe River	130	5.05	38.8	2.811	0.625	0.222
Nova Scotia						
Annapolis River (Wilmot)	546	12.3	22.5	7.941	1.899	0.239
Annapolis River (Lawrencetown)	1020	23.7	23.2	16.78	4.264	0.254
Beaverbank River	96.9	3.00	31.0	1.702	0.127	0.075
Fraser Brook	10.1	0.239	23.7	0.13	0.017	0.131
Kelley River(Mill Creek)	63.2	1.85	29.3	1.036	0.165	0.159
Wallace River	298	8.9	29.9	5.279	1.066	0.202
River John	249	6.56	26.3	3.115	0.396	0.127
Middle River of Pictou	92.2	2.65	28.7	1.449	0.199	0.137
South River	177	5.26	29.7	2.837	0.533	0.188
Roseway River	495	16.2	32.7	12.98	2.378	0.183
Mersey River	295	8.42	28.5	6.06	0.901	0.149
LaHave River	1250	34.4	27.5	24.04	2.891	0.120
Gold River	370	11.0	29.7	7.432	0.589	0.079
Sackville River	146	5.02	34.4	3.045	0.334	0.110
Musquodoboit	650	20.1	30.9	12.51	1.708	0.137
Liscomb	389	16.0	41.1	9.856	2.054	0.208
St. Marys River	1350	42.9	31.8	26.65	3.900	0.146
Clam Harbour River	45.1	1.62	35.9	0.879	0.094	0.107
River Inhabitants	193	7.01	36.3	4.031	0.976	0.242
Northeast Margaree	368	17.2	46.7	10.75	4.201	0.391
Southwest Margaree River	357	12.5	35.0	11.80	3.446	0.292
Cheticamp River	190	10.9	57.4	5.327	2.218	0.416
Wreck Cove Brook	31	1.46	47.1	0.772	0.178	0.231
Indian Brook	125	9.92	79.4	4.681	1.234	0.264
Grand River	120	4.38	36.5	3.613	0.693	0.192
Macaskills Brook	17.2	0.629	36.6	0.308	0.033	0.107
Prince Edward Island						
Carruthers Brook	46.8	0.938	20.0	0.478	0.172	0.360
Dunk River	114	2.540	22.3	1.758	0.969	0.551
Wilmot River	45.4	0.918	20.2	0.608	0.340	0.559
Winter River	37.5	0.662	17.7	0.435	0.169	0.389
West River	70.1	1.700	24.3	1.203	0.623	0.518
Bear River	14.8	0.320	21.6	0.208	0.073	0.351

Table 3. Regional regression equations for the mean annual flow and median flow by province (Maritime Provinces)

Province	a	b	R^2
	Mean annual flow (MAF)		
New Brunswick[1]	0.0247	0.980	0.986
Nova Scotia[2]	0.0413	0.961	0.949
Prince Edward Island[3]	0.0173	1.050	0.980
	Median flow (Q_{50})		
New Brunswick[1]	0.00989	1.003	0.963
Nova Scotia[2]	0.01722	1.032	0.955
Prince Edward Island[3]	0.00964	1.087	0.945

1. For basins ranging from 29.6 km^2 to 14 770 km^2
2. For basins ranging from 10.1 km^2 to 1 350 km^2
3. For basins ranging from 14.8 km^2 to 114 km^2

Table 4. Results of flood frequency analysis for different recurence intervals within the Maritime Provinces (m^3/s).

River	QMF	QF2	QF5	QF10	QF20	QF50	QF100
				New Brunswick			
Saint John River	2354	2317	2980	3347	3661	4027	4279
St. Francis River	204	195	261	302	339	385	418
Liemstone Stream	35.7	33.6	42.8	49.1	55.4	63.7	70.1
Meduxnekeag River	254	236	325	385	442	517	575
Shogomoc Stream	39.3	37.7	50.3	58.0	65.0	73.6	79.9
Middle Branch Nashwaaksis Stream	6.94	6.12	8.82	10.9	13.2	16.4	19.1
Nashwaak River	349	316	455	552	649	779	880
North Branch Oromocto River	139	120	174	218	266	338	399
Canaan River	150	149	185	204	220	239	251
Kennebecasis River	260	232	336	414	494	607	697
Lepreau River	73.7	59.9	93.6	123.3	157.7	211.2	258.5
Restigouche River	597	567	754	872	981	1120	1221
Upsalquitch River	374	354	484	566	642	738	808
Tetagouche River	78.7	73.8	101	118	135	156	173
Jacquet River	119	113	145	165	184	207	224
Bass River	43.9	39.1	54.8	66.9	79.8	98.3	114
Southwest Miramichi River	905	852	1154	1348	1531	1764	1939
Renous River	148	131	186	228	273	336	388
Little Southwest Miramichi River	266	225	339	435	540	700	836
Catamaran Brook	6.34	5.40	7.95	10.3	13.2	17.7	21.9
Northwest Miramichi River	202	182	262	319	376	452	513
Coal Branch River	46.5	44.8	58.1	66.2	73.5	82.6	89.1
Point Wolfe River	67.0	60.8	86.3	105	123	148	168
				Nova Scotia			
Annapolis River (Wilmot)	95.8	85.1	123	151	181	222	256
Annapolis River (Lawrencetown)	174	147	217	277	345	449	540
Beaverbank River	29.1	26.6	37.2	44.5	51.8	61.5	69.1
Fraser Brook	2.46	2.35	2.94	3.28	3.58	3.94	4.20
Kelley River(Mill Creek)	20.6	17.6	25.4	32.3	40.2	52.5	63.3
Wallace River	90.4	82.9	120	144	168	199	223
River John	82.7	80.7	103	115	126	139	149
Middle River of Pictou	29.1	27.0	36.1	42.4	48.7	57.1	63.7
South River	55.6	47.0	67.3	86.3	109	146	180
Roseway River	72.5	64.3	88.8	108	129	161	187
Mersey River	46.0	40.9	55.5	67.0	79.4	97.5	113
LaHave River	249	211	319	405	498	634	748
Gold River	80.1	78.0	98.6	111	121	134	144
Sackville River	44.0	41.4	55.8	65.2	74.0	85.4	93.9
Musquodoboit	142	126	169	206	248	311	365
Liscomb	123	105	153	196	245	322	389
St. Marys River	447	412	565	671	776	916	1025
Clam Harbour River	19.4	17.0	24.7	30.8	37.5	47.4	55.7
River Inhabitants	67.3	63.9	80.8	92.1	103	117	128
Northeast Margaree	182	167	231	275	319	379	425
Southwest Margaree River	38.3	37.5	44.5	48.6	52.2	56.7	59.9
Cheticamp River	124	119	153	174	193	217	235
Wreck Cove Brook	16.2	12.1	20.0	27.3	35.9	49.6	62.0
Indian Brook	114	101	150	185	220	269	308
Grand River	17.7	16.9	21.4	24.2	26.8	30.2	32.7
Macaskills Brook	9.21	7.95	11.7	14.8	18.3	23.4	27.9
				Prince Edward Island			
Carruthers Brook	10.4	9.18	13.2	16.2	19.3	23.8	27.4
Dunk River	31.1	27.4	42.6	53.4	64.3	79.1	90.8
Wilmot River	11.9	11.3	14.9	17.2	19.3	22.0	23.9
Winter River	6.51	6.18	8.02	9.20	10.3	11.8	12.8
West River	14.5	13.3	18.4	22.0	25.6	30.4	34.1
Bear River	2.99	2.48	3.85	5.10	6.59	8.97	11.1

Table 5. High flow regional regression equations within the Maritime Provinces (m^3/s).

	High Flow		
	a	b	R^2
	New Brunswick[1] (N=23)		
QMF *	0.3927	0.910	0.974
2-year	0.3296	0.924	0.977
5-year	0.4860	0.914	0.973
10-year	0.6289	0.901	0.969
20-year	0.7974	0.887	0.963
50-year	1.065	0.869	0.952
100-year	1.307	0.856	0.942
	Nova Scotia[2] (N=26)		
QMF	0.7014	0.831	0.833
2-year	0.6167	0.836	0.839
5-year	0.8648	0.833	0.823
10-year	1.050	0.831	0.811
20-year	1.241	0.830	0.798
50-year	1.508	0.829	0.778
100-year	1.721	0.829	0.763
	Prince Edward Island[3] (N=6)		
QMF	0.1316	1.135	0.967
2-year	0.1063	1.163	0.972
5-year	0.1534	1.159	0.959
10-year	0.2074	1.131	0.941
20-year	0.2791	1.097	0.915
50-year	0.4065	1.049	0.872
100-year	0.5330	1.013	0.834

* QMF = Mean Annual Flood

[1] For basins ranging from 29.6 km^2 to 14700 km^2

[2] For basins ranging from 10.1 to 1350 km^2

[3] For basins ranging from 14.8 to 114 km^2

Table 6. Result of the index flood for five differents recurence intervals within the Maritime Provinces (using the 2-year, QF2, as the index).

River	QF5/QF2	QF10/QF2	QF20/QF2	QF50/QF2	QF100/QF2
			New Brunswick		
Saint John River	1.3	1.4	1.6	1.7	1.8
St. Francis River	1.3	1.5	1.7	2.0	2.1
Liemstone Stream	1.3	1.5	1.6	1.9	2.1
Meduxnekeag River	1.4	1.6	1.9	2.2	2.4
Shogomoc Stream	1.3	1.5	1.7	2.0	2.1
Middle Branch Nashwaaksis Stream	1.4	1.8	2.2	2.7	3.1
Nashwaak River	1.4	1.7	2.1	2.5	2.8
North Branch Oromocto River	1.5	1.8	2.2	2.8	3.3
Canaan River	1.2	1.4	1.5	1.6	1.7
Kennebecasis River	1.5	1.8	2.1	2.6	3.0
Lepreau River	1.6	2.1	2.6	3.5	4.3
Restigouche River	1.3	1.5	1.7	2.0	2.2
Upsalquitch River	1.4	1.6	1.8	2.1	2.3
Tetagouche River	1.4	1.6	1.8	2.1	2.3
Jacquet River	1.3	1.5	1.6	1.8	2.0
Bass River	1.4	1.7	2.0	2.5	2.9
Southwest Miramichi River	1.4	1.6	1.8	2.1	2.3
Renous River	1.4	1.7	2.1	2.6	3.0
Little Southwest Miramichi River	1.5	1.9	2.4	3.1	3.7
Catamaran Brook	1.5	1.9	2.4	3.3	4.1
Northwest Miramichi River	1.4	1.8	2.1	2.5	2.8
Coal Branch River	1.3	1.5	1.6	1.8	2.0
Point Wolfe River	1.4	1.7	2.0	2.4	2.8
mean	*1.4*	*1.7*	*1.9*	*2.3*	*2.7*
cv (%)	*5.8*	*10.6*	*15.4*	*21.7*	*26.5*
			Nova Scotia		
Annapolis River (Wilmot)	1.4	1.8	2.1	2.6	3.0
Annapolis River (Lawrencetown)	1.5	1.9	2.4	3.1	3.7
Beaverbank River	1.4	1.7	1.9	2.3	2.6
Fraser Brook	1.2	1.4	1.5	1.7	1.8
Kelley River(Mill Creek)	1.4	1.8	2.3	3.0	3.6
Wallace River	1.4	1.7	2.0	2.4	2.7
River John	1.3	1.4	1.6	1.7	1.8
Middle River of Pictou	1.3	1.6	1.8	2.1	2.4
South River	1.4	1.8	2.3	3.1	3.8
Roseway River	1.4	1.7	2.0	2.5	2.9
Mersey River	1.4	1.6	1.9	2.4	2.7
LaHave River	1.5	1.9	2.4	3.0	3.5
Gold River	1.3	1.4	1.6	1.7	1.8
Sackville River	1.3	1.6	1.8	2.1	2.3
Musquodoboit	1.3	1.6	2.0	2.5	2.9
Liscomb	1.5	1.9	2.3	3.1	3.7
St. Marys River	1.4	1.6	1.9	2.2	2.5
Clam Harbour River	1.4	1.8	2.2	2.8	3.3
River Inhabitants	1.3	1.4	1.6	1.8	2.0
Northeast Margaree	1.4	1.6	1.9	2.3	2.5
Southwest Margaree River	1.2	1.3	1.4	1.5	1.6
Cheticamp River	1.3	1.5	1.6	1.8	2.0
Wreck Cove Brook	1.7	2.3	3.0	4.1	5.1
Indian Brook	1.5	1.8	2.2	2.7	3.1
Grand River	1.3	1.4	1.6	1.8	1.9
Macaskills Brook	1.5	1.9	2.3	2.9	3.5
mean	*1.4*	*1.7*	*2.0*	*2.4*	*2.8*
cv (%)	*7.5*	*12.9*	*18.1*	*24.7*	*29.6*
			Prince Edward Island		
Carruthers Brook	1.4	1.8	2.1	2.6	3.0
Dunk River	1.6	1.9	2.3	2.9	3.3
Wilmot River	1.3	1.5	1.7	1.9	2.1
Winter River	1.3	1.5	1.7	1.9	2.1
West River	1.4	1.7	1.9	2.3	2.6
Bear River	1.6	2.1	2.7	3.6	4.5
mean	1.4	1.7	2.1	2.5	2.9
cv (%)	7.7	13.1	18.4	25.5	30.8

Table 7. Result of the index flood for five differents recurence intervals within the Maritime Provinces (using the Mean Annual Flood, QMF, as the index).

River	QF5/QMF	Q10/QMF	Q20/QMF	Q50/QMF	Q100/QMF
			New Brunswick		
Saint John River	1.3	1.4	1.6	1.7	1.8
St. Francis River	1.3	1.5	1.7	1.9	2.0
Liemstone Stream	1.2	1.4	1.6	1.8	2.0
Meduxnekeag River	1.3	1.5	1.7	2.0	2.3
Shogomoc Stream	1.3	1.5	1.7	1.9	2.0
Middle Branch Nashwaaksis Stream	1.3	1.6	1.9	2.4	2.7
Nashwaak River	1.3	1.6	1.9	2.2	2.5
North Branch Oromocto River	1.2	1.6	1.9	2.4	2.9
Canaan River	1.2	1.4	1.5	1.6	1.7
Kennebecasis River	1.3	1.6	1.9	2.3	2.7
Lepreau River	1.3	1.7	2.1	2.9	3.5
Restigouche River	1.3	1.5	1.6	1.9	2.0
Upsalquitch River	1.3	1.5	1.7	2.0	2.2
Tetagouche River	1.3	1.5	1.7	2.0	2.2
Jacquet River	1.2	1.4	1.5	1.7	1.9
Bass River	1.2	1.5	1.8	2.2	2.6
Southwest Miramichi River	1.3	1.5	1.7	1.9	2.1
Renous River	1.3	1.5	1.8	2.3	2.6
Little Southwest Miramichi River	1.3	1.6	2.0	2.6	3.1
Catamaran Brook	1.3	1.6	2.1	2.8	3.5
Northwest Miramichi River	1.3	1.6	1.9	2.2	2.5
Coal Branch River	1.2	1.4	1.6	1.8	1.9
Point Wolfe River	1.3	1.6	1.8	2.2	2.5
mean	*1.3*	*1.5*	*1.8*	*2.1*	*2.4*
cv (%)	*2.0*	*5.6*	*10.1*	*16.3*	*20.9*
			Nova Scotia		
Annapolis River (Wilmot)	1.3	1.6	1.9	2.3	2.7
Annapolis River (Lawrencetown)	1.2	1.6	2.0	2.6	3.1
Beaverbank River	1.3	1.5	1.8	2.1	2.4
Fraser Brook	1.2	1.3	1.5	1.6	1.7
Kelley River(Mill Creek)	1.2	1.6	1.9	2.5	3.1
Wallace River	1.3	1.6	1.9	2.2	2.5
River John	1.2	1.4	1.5	1.7	1.8
Middle River of Pictou	1.2	1.5	1.7	2.0	2.2
South River	1.2	1.6	2.0	2.6	3.2
Roseway River	1.2	1.5	1.8	2.2	2.6
Mersey River	1.2	1.5	1.7	2.1	2.4
LaHave River	1.3	1.6	2.0	2.5	3.0
Gold River	1.2	1.4	1.5	1.7	1.8
Sackville River	1.3	1.5	1.7	1.9	2.1
Musquodoboit	1.2	1.4	1.7	2.2	2.6
Liscomb	1.2	1.6	2.0	2.6	3.2
St. Marys River	1.3	1.5	1.7	2.1	2.3
Clam Harbour River	1.3	1.6	1.9	2.4	2.9
River Inhabitants	1.2	1.4	1.5	1.7	1.9
Northeast Margaree	1.3	1.5	1.8	2.1	2.3
Southwest Margaree River	1.2	1.3	1.4	1.5	1.6
Cheticamp River	1.2	1.4	1.6	1.8	1.9
Wreck Cove Brook	1.2	1.7	2.2	3.1	3.8
Indian Brook	1.3	1.6	1.9	2.4	2.7
Grand River	1.2	1.4	1.5	1.7	1.9
Macaskills Brook	1.3	1.6	2.0	2.5	3.0
mean	*1.2*	*1.5*	*1.8*	*2.2*	*2.5*
cv (%)	*3.1*	*7.1*	*11.9*	*18.2*	*23.0*
			Prince Edward Island		
Carruthers Brook	1.3	1.6	1.9	2.3	2.6
Dunk River	1.4	1.7	2.1	2.5	2.9
Wilmot River	1.3	1.5	1.6	1.9	2.0
Winter River	1.2	1.4	1.6	1.8	2.0
West River	1.3	1.5	1.8	2.1	2.4
Bear River	1.3	1.7	2.2	3.0	3.7
mean	*1.3*	*1.6*	*1.9*	*2.3*	*2.6*
cv (%)	*3.6*	*8.1*	*13.2*	*20.0*	*25.2*

Table 8. Results of the low flow analysis for different recurence intervals within the Maritime Provinces.

River	QML	QL2	QL5	QL10	QL20	QL50
			New Brunswick			
Saint John River	32.0	30.5	22.9	20.0	18.1	16.6
St. Francis River	3.45	3.30	2.49	2.17	1.97	1.80
Liemstone Stream	0.433	0.440	0.325	0.263	0.212	0.158
Meduxnekeag River	1.48	1.17	0.677	0.547	0.487	0.451
Shogomoc Stream	0.322	0.277	0.130	0.0894	0.0690	0.0563
Middle Branch Nashwaaksis Stream	0.0154	0.0132	0.0081	0.0066	0.0058	0.0053
Nashwaak River	4.09	3.79	2.86	2.55	2.38	2.25
North Branch Oromocto River*	0.503	0.339	0.101	0.0427	0.0166	0.0019
Canaan River	0.474	0.419	0.254	0.203	0.176	0.158
Kennebecasis River	2.60	2.53	1.80	1.50	1.29	1.11
Lepreau River	0.489	0.444	0.212	0.131	0.0836	0.0478
Restigouche River	9.69	9.41	7.49	6.70	6.17	5.71
Upsalquitch River	5.58	5.44	4.24	3.82	3.58	3.39
Tetagouche River	0.744	0.722	0.521	0.443	0.394	0.353
Jacquet River	1.01	0.967	0.725	0.630	0.570	0.520
Bass River	0.102	0.092	0.0487	0.0329	0.0232	0.0156
Southwest Miramichi River	19.6	18.7	14.6	13.0	11.9	11.1
Renous River	1.46	1.33	0.926	0.791	0.714	0.657
Little Southwest Miramichi River	5.15	5.03	3.63	3.00	2.56	2.15
Catamaran Brook	0.0406	0.0384	0.0265	0.0219	0.0189	0.0164
Northwest Miramichi River	2.68	2.61	2.05	1.82	1.66	1.52
Coal Branch River	0.216	0.205	0.136	0.109	0.0905	0.0752
Point Wolfe River	0.354	0.306	0.188	0.151	0.131	0.118
			Nova Scotia			
Annapolis River (Wilmot)	1.29	1.26	0.883	0.708	0.581	0.461
Annapolis River (Lawrencetown)	2.50	2.28	1.66	1.45	1.34	1.26
Beaverbank River*	0.063	0.024	0.0034	0.0009	0.0002	0.0000
Fraser Brook*	0.006	0.004	0.0012	0.0005	0.0001	0.0000
Kelley River(Mill Creek)	0.078	0.072	0.0451	0.0348	0.0283	0.0231
Wallace River	0.719	0.692	0.456	0.353	0.283	0.219
River John	0.277	0.212	0.124	0.0945	0.0776	0.0652
Middle River of Pictou	0.107	0.0767	0.0318	0.0181	0.0109	0.0060
South River	0.311	0.356	0.214	0.147	0.0980	0.0505
Roseway River	1.489	1.215	0.617	0.416	0.300	0.216
Mersey River	0.576	0.419	0.144	0.0732	0.0402	0.0209
LaHave River	2.03	1.55	0.651	0.394	0.265	0.183
Gold River*	0.298	0.225	0.0771	0.0351	0.0138	0.0003
Sackville River	0.120	0.084	0.0283	0.0142	0.0076	0.0038
Musquodoboit	0.999	0.814	0.334	0.205	0.142	0.103
Liscomb	1.03	0.801	0.381	0.245	0.169	0.115
St. Marys River	2.03	1.60	0.677	0.425	0.302	0.227
Clam Harbour River**	0.0324	0.0239	0.0077	0.0033	0.0011	0.0000
River Inhabitants	0.616	0.600	0.433	0.358	0.306	0.257
Northeast Margaree	2.96	3.11	2.37	2.01	1.75	1.49
Southwest Margaree River	2.42	2.46	1.56	1.16	0.881	0.628
Cheticamp River	1.59	1.54	1.19	1.04	0.942	0.854
Wreck Cove Brook	0.0970	0.0861	0.0516	0.0341	0.0204	0.0064
Indian Brook	0.708	0.643	0.366	0.263	0.199	0.149
Grand River	0.299	0.263	0.101	0.0533	0.0291	0.0135
Macaskills Brook	0.0120	0.0083	0.0030	0.0017	0.0011	0.0008
			Prince Edward Island			
Carruthers Brook	0.140	0.136	0.1053	0.0921	0.0830	0.0750
Dunk River	0.771	0.786	0.552	0.423	0.315	0.196
Wilmot River	0.291	0.288	0.228	0.199	0.178	0.158
Winter River	0.088	0.086	0.0490	0.0318	0.0193	0.0074
West River	0.506	0.507	0.448	0.417	0.392	0.365
Bear River	0.0530	0.0509	0.0403	0.0363	0.0339	0.0319

* Stations excluded from the regression analysis because they presented a different low flow behaviour

** QL50 was not part of the regression

Table 9. Low flow regional equations within the Maritime Provinces (m^3/s).

	Low Flow		
	$a \times 10^{-3}$	b	R^2
	New Brunswick[1] (N=22)		
QML	0.5150	1.204	0.945
2-year	0.4443	1.215	0.939
5-year	0.2180	1.265	0.924
10-year	0.1471	1.296	0.916
20-year	0.1072	1.322	0.909
50-year	0.0767	1.351	0.899
	Nova Scotia[2] (N=23)		
QML	0.8476	1.175	0.791
2-year	0.6501	1.196	0.749
5-year	0.2510	1.250	0.664
10-year	0.1229	1.307	0.620
20-year	0.0534	1.393	0.592
50-year (n=22)[4]	0.0501	1.353	0.554
	Prince Edward Island[3] (N=6)		
QML *	0.9381	1.407	0.857
2-year	0.8282	1.437	0.858
5-year	0.6104	1.439	0.781
10-year	0.5642	1.410	0.696
20-year	0.5620	1.361	0.581
50-year	0.5802	1.275	0.375

* QLF = Mean annual low flow

[1] For basins ranging from 29.6 km^2 to 14700 km^2

[2] For basins ranging from 10.1 to 1350 km^2

[3] For basins ranging from 14.8 to 114 km^2

[4] Clam Habour River was excluded from this regression equation

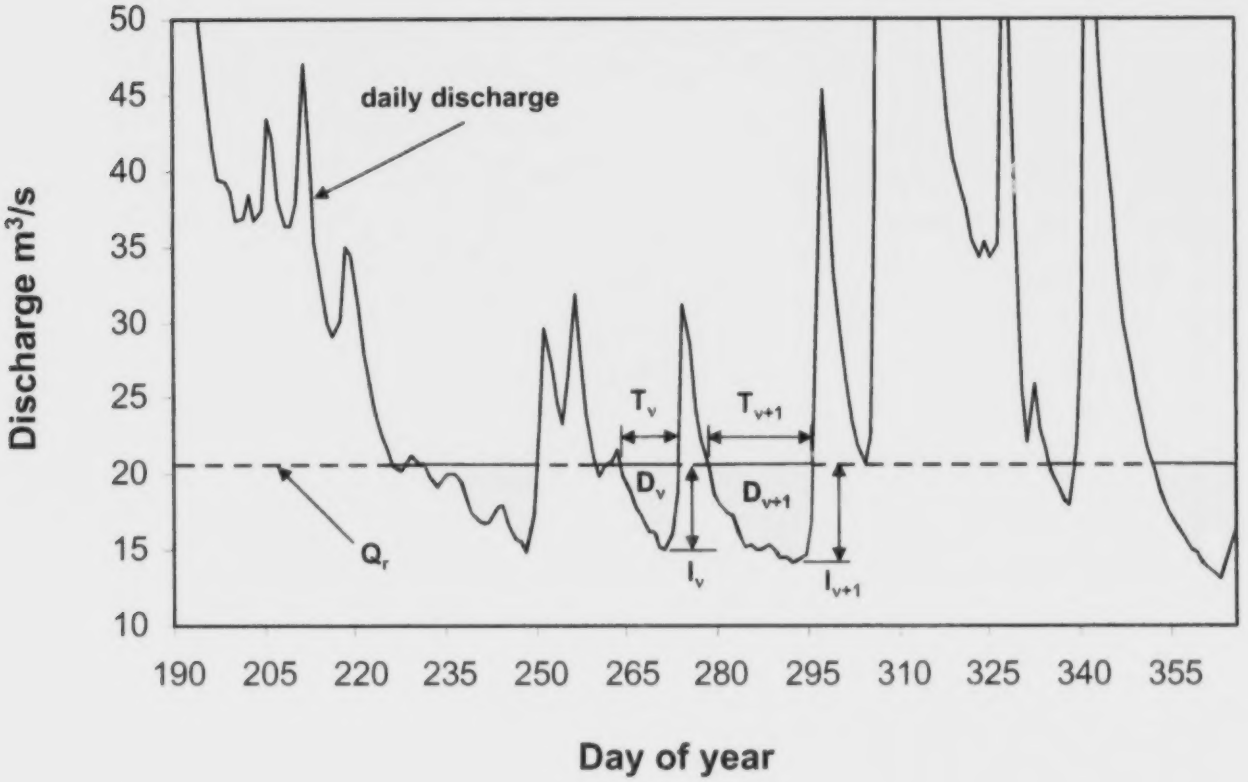

Figure 1. Illustrative example of the partial duration series approach for low flows (DBT approach).

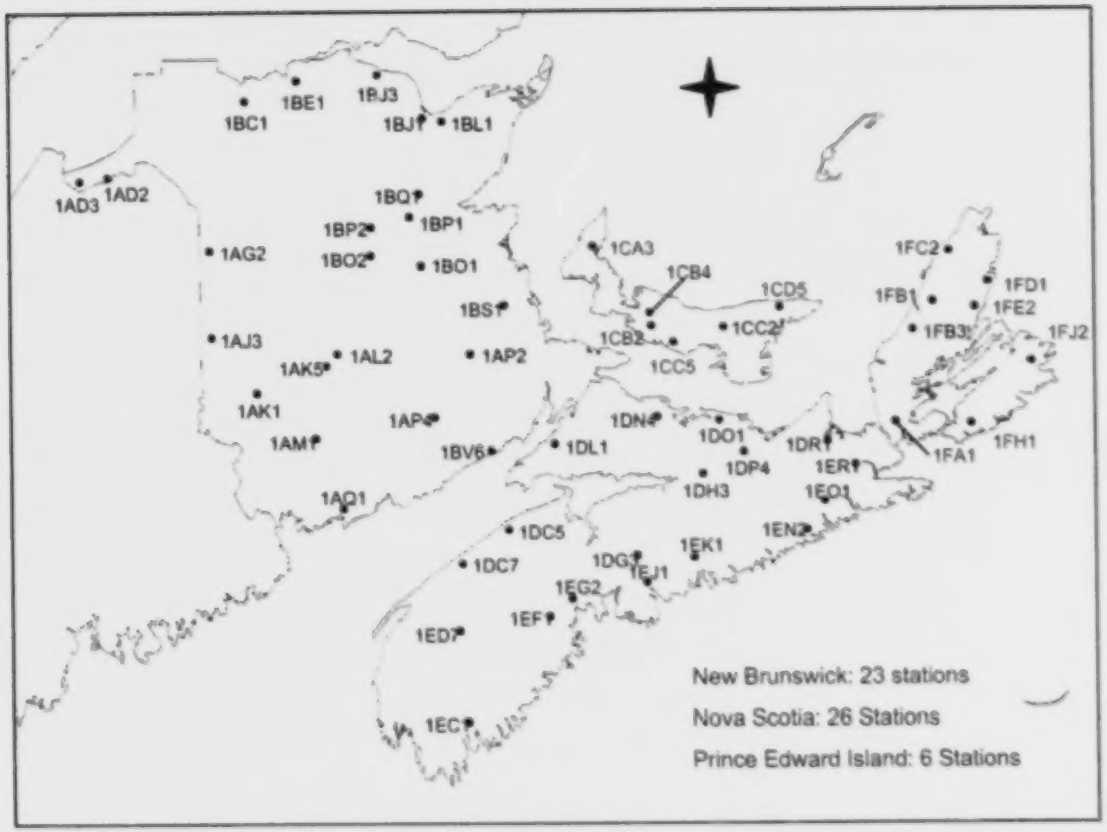

Figure 2. Location of selected hydrometric stations throughout the Maritime Provinces (55 hydrometric stations).

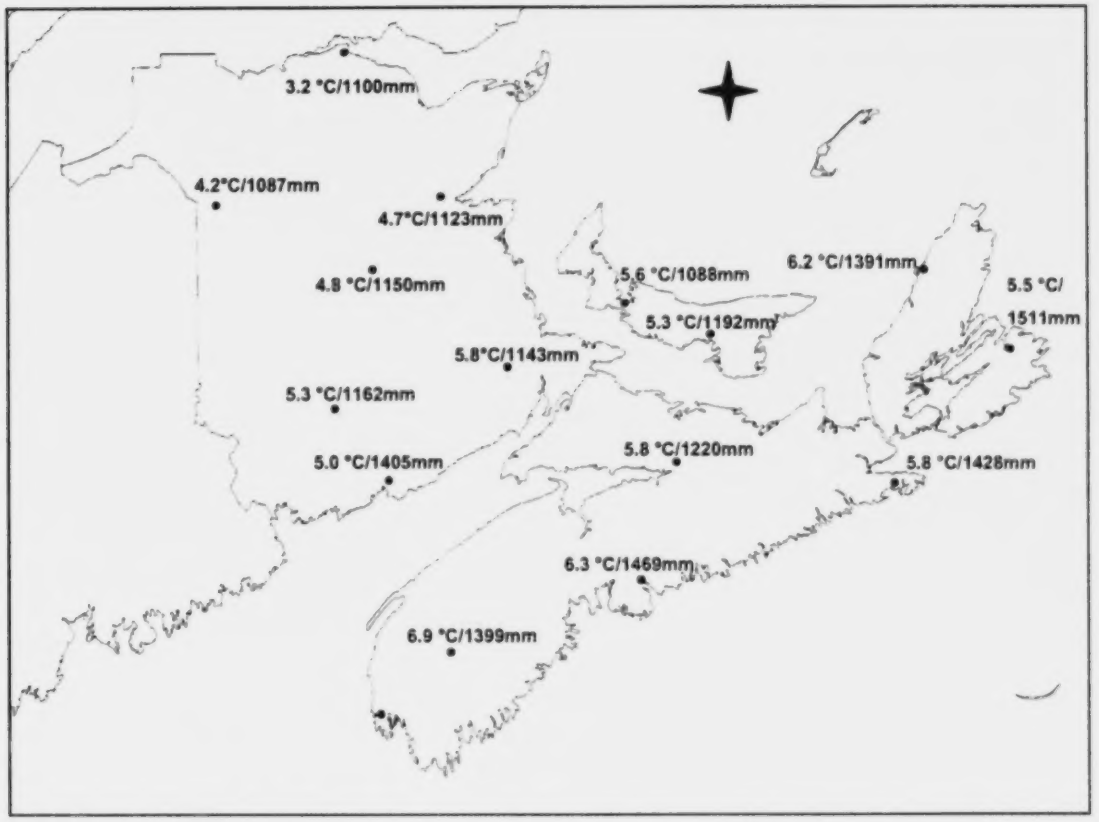

Figure 3. Average annual precipitation and air temperature for selected sites across the Maritime Provinces.

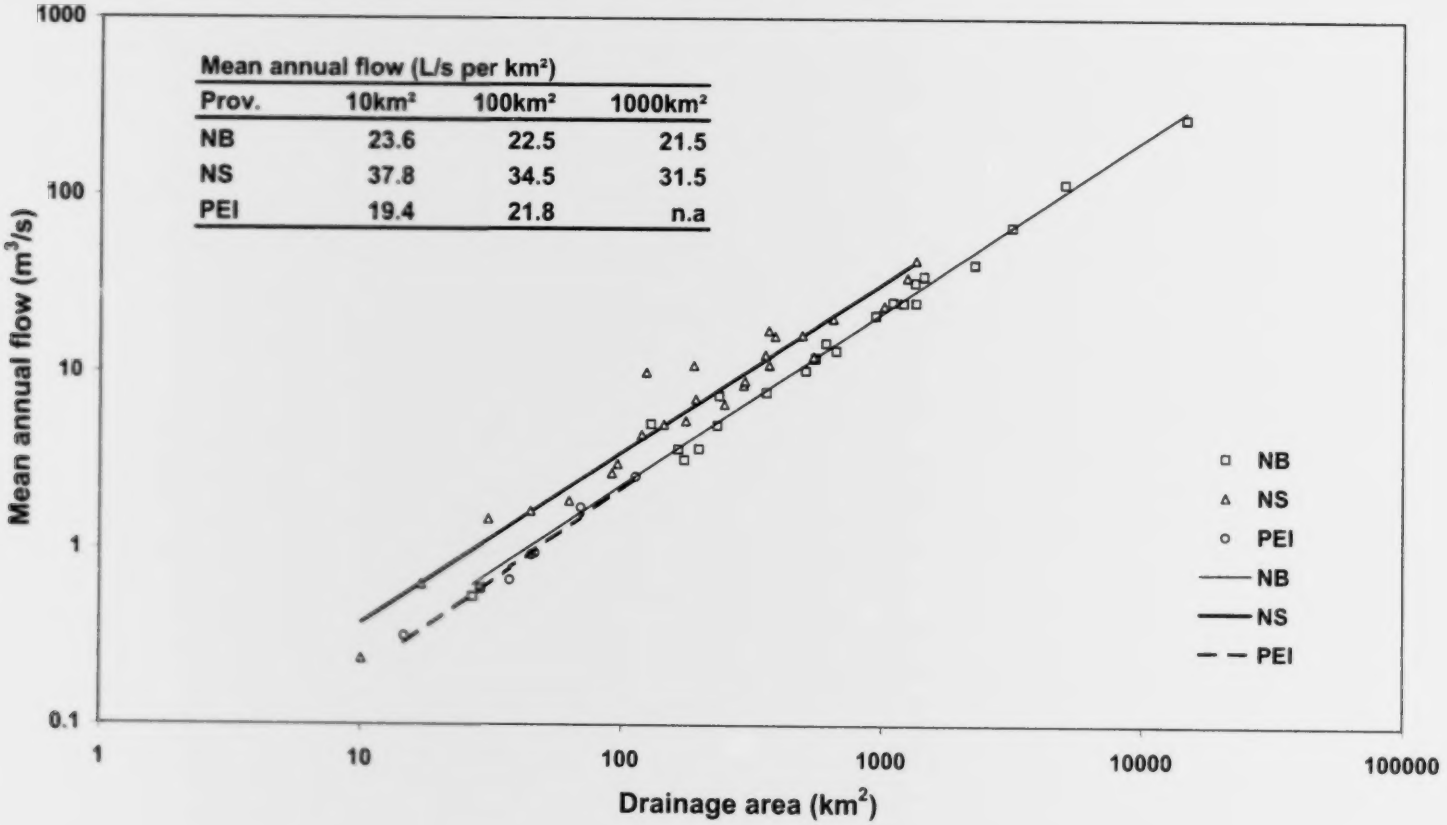

Figure 4. Relation between the mean annual flow (MAF) and the drainage area for all stations throughout the Maritime Provinces.

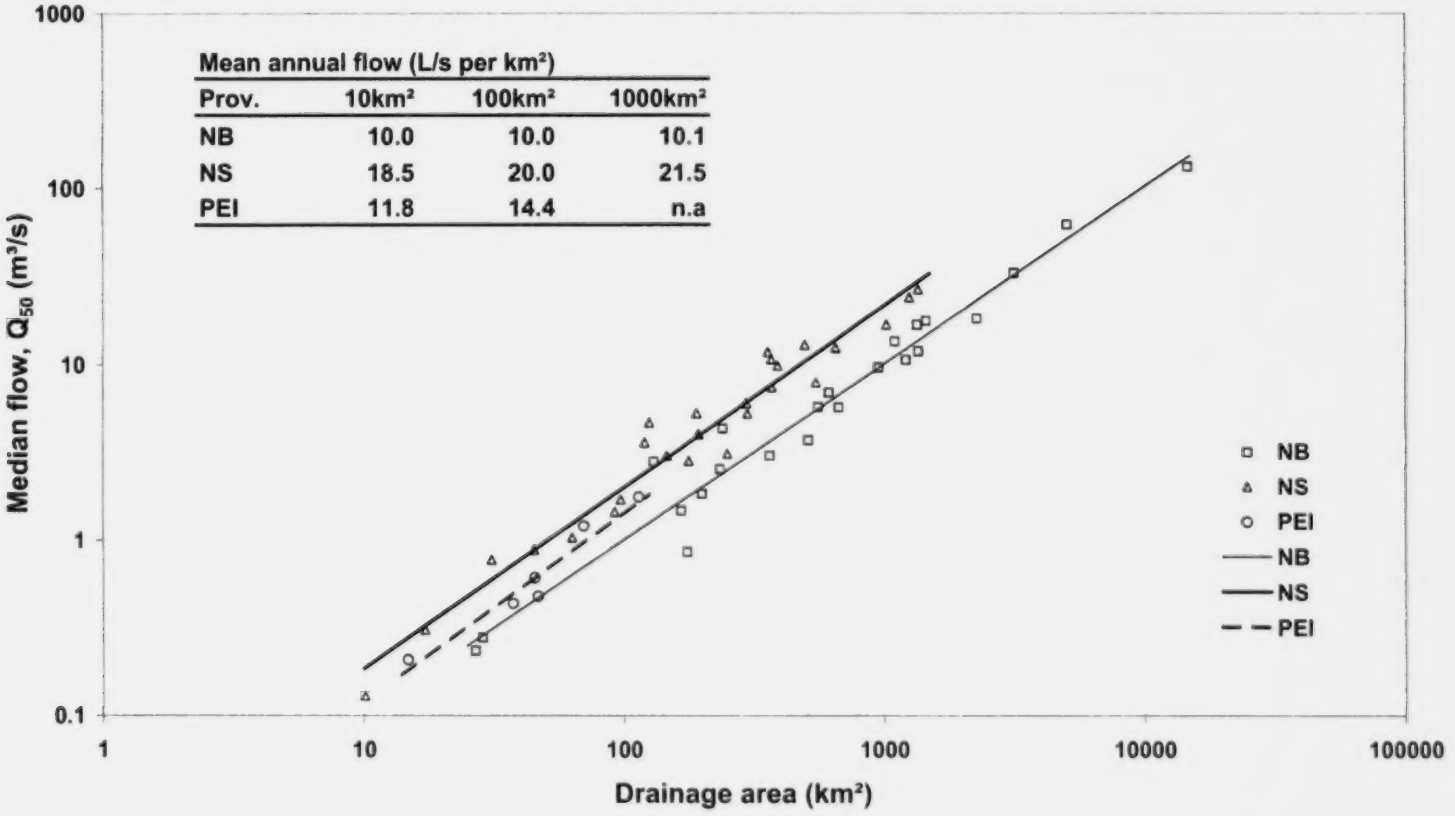

Figure 5. Relation between the median flow (Q_{50}) and the drainage area for all stations throughout the Maritime Provinces.

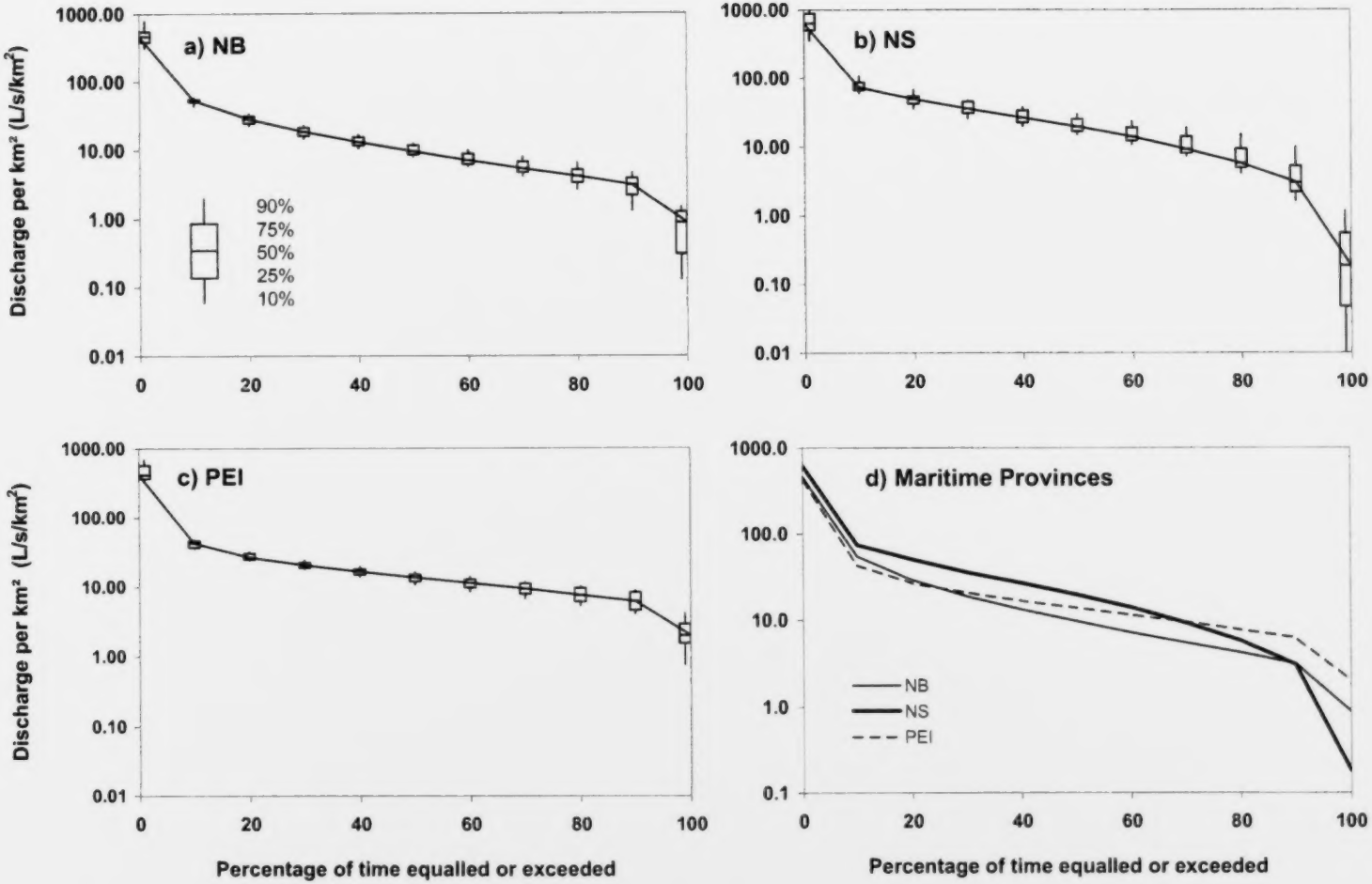

Figure 6. Flow duration curves by province (box plots represent flows between 10% and 90%, see above).

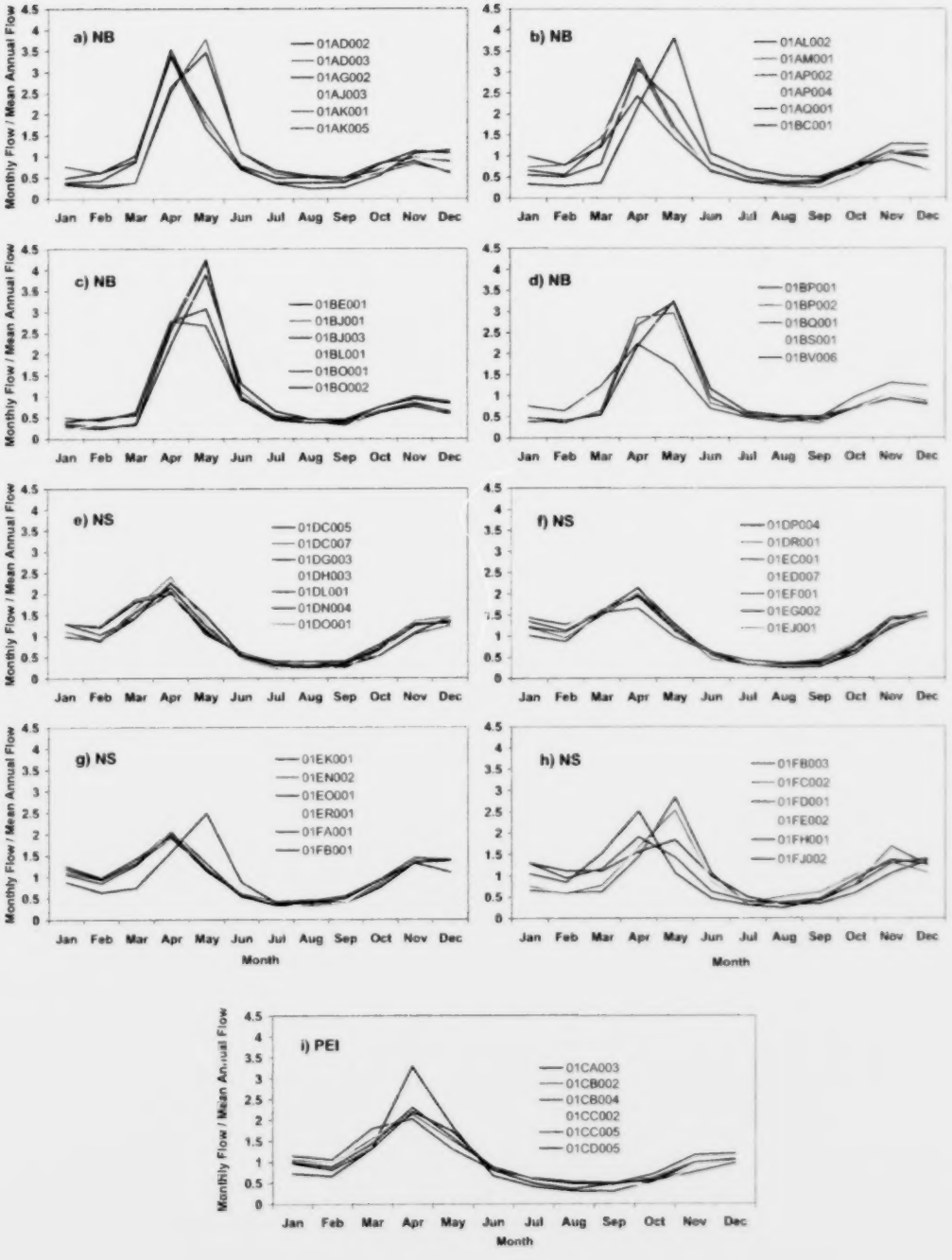

Figure 7. Monthly flows (expressed as a ratio of monthly flows to the mean annual flow) for analysed hydrometric stations throughout the Maritime Provinces.

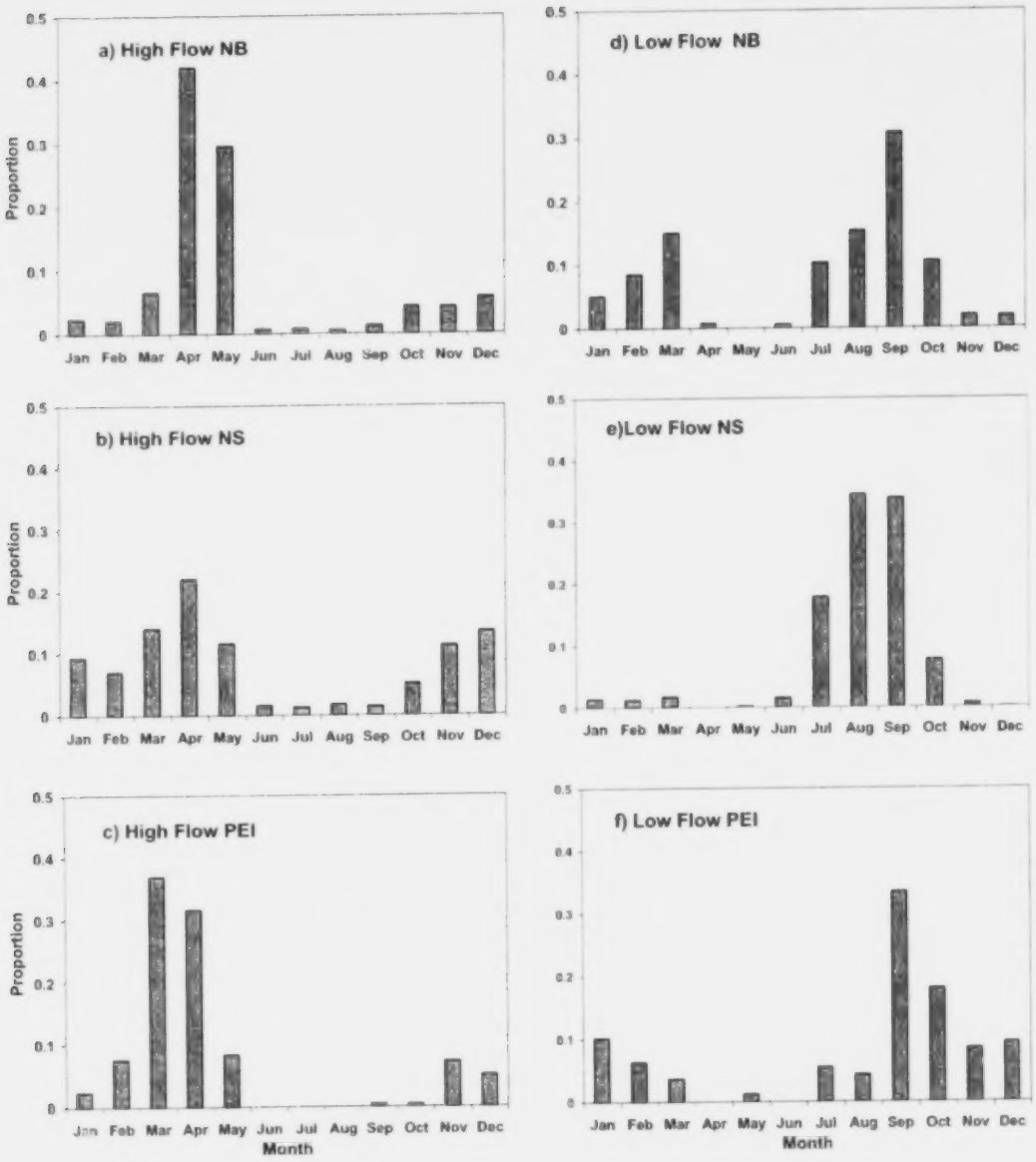
a) High Flow NB
d) Low Flow NB
b) High Flow NS
e)Low Flow NS
c) High Flow PEI
f) Low Flow PEI
Proportion
Month
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
0 0.1 0.2 0.3 0.4 0.5

Figure 8. Proportion of high and low flow events by month throughout the Maritime Provinces.

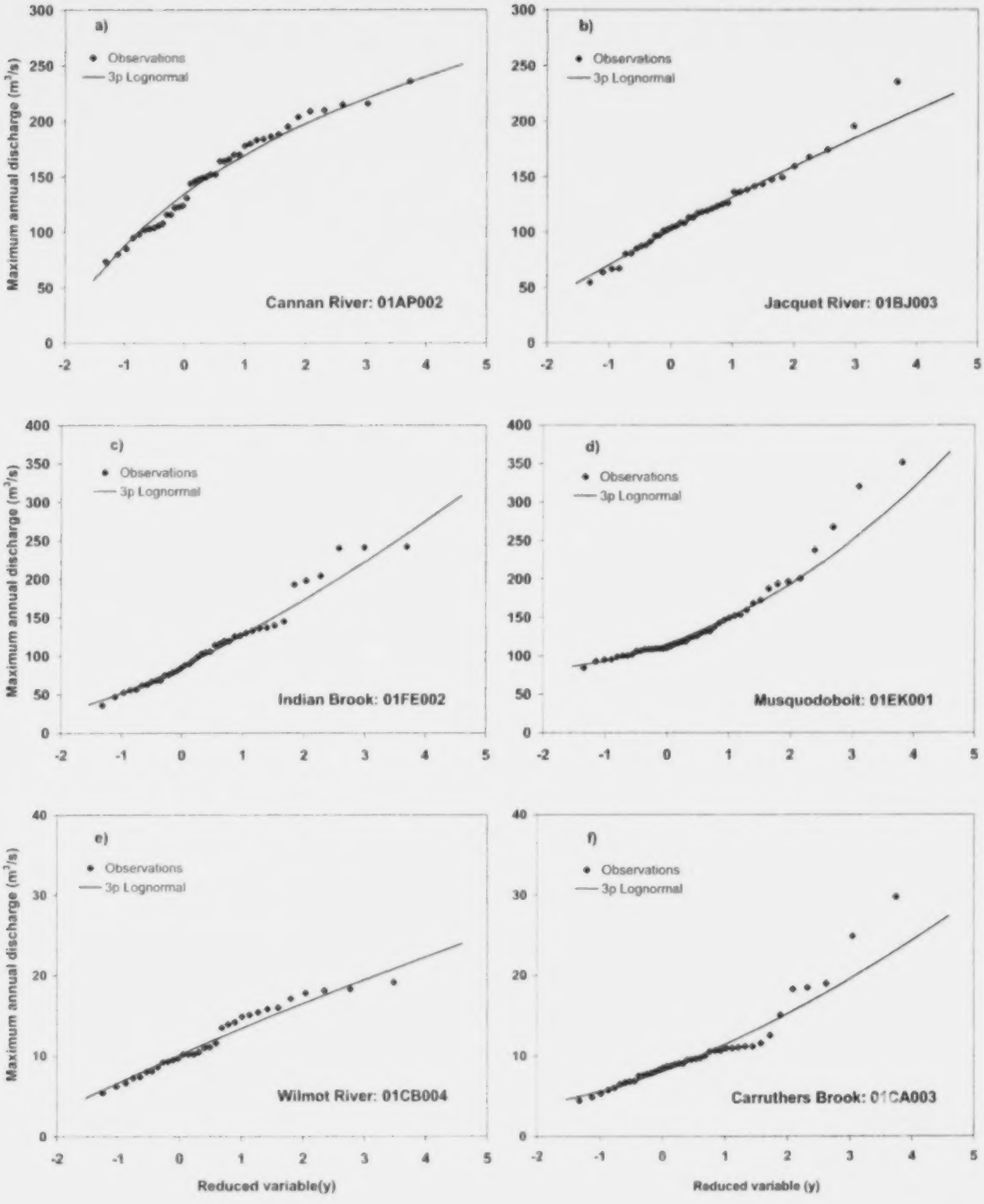

Figure 9. Examples of flood frequency plots for selected stations throughout the Maritime Provinces (data are plotted using a Gumbel paper).

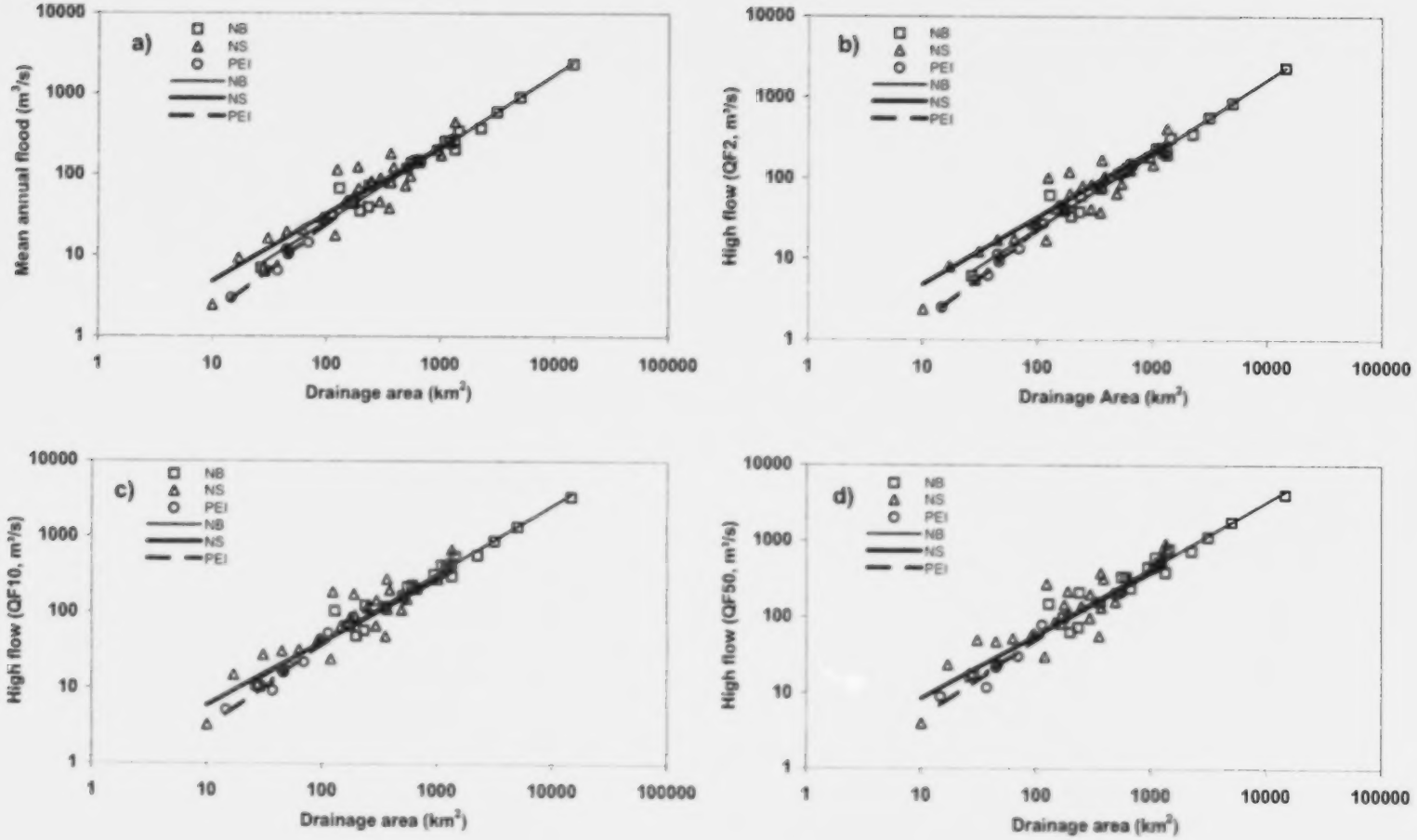

Figure 10. Relation between high flow data and drainage area throughout the Maritime Provinces, a) Mean annual flood, b) QF2, c) QF10 and d) QF50.

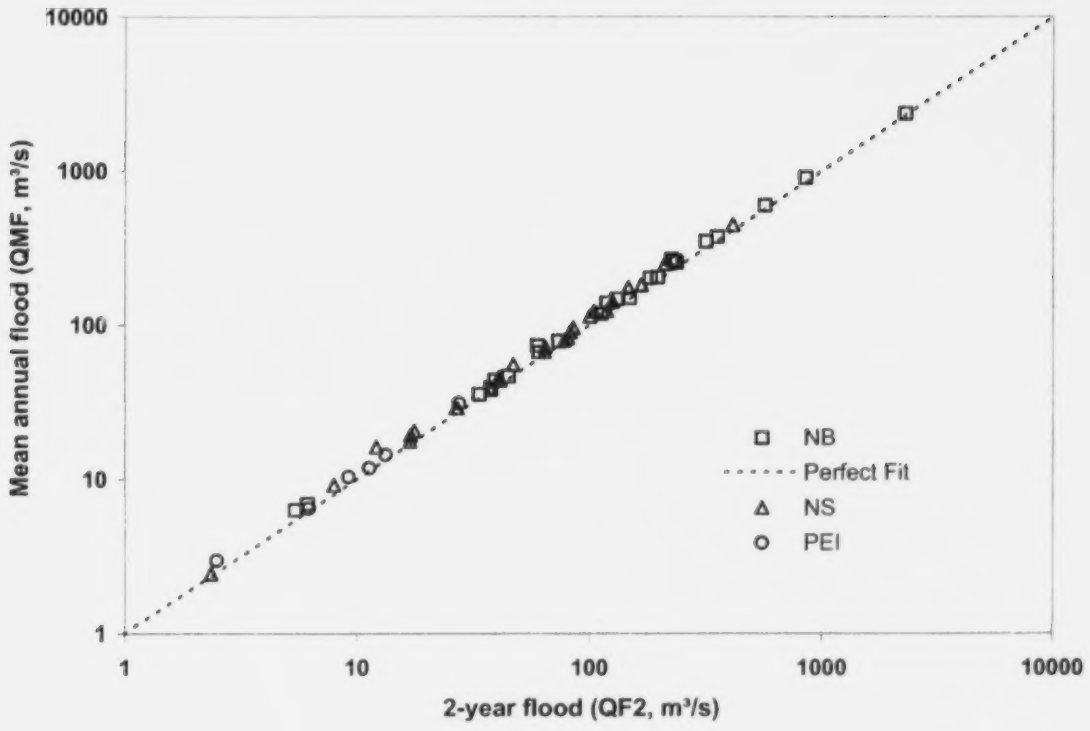

Figure 11. Plot of the mean annual flood vs. the 2-year flood for all analysed stations throughout the Maritime Provinces.

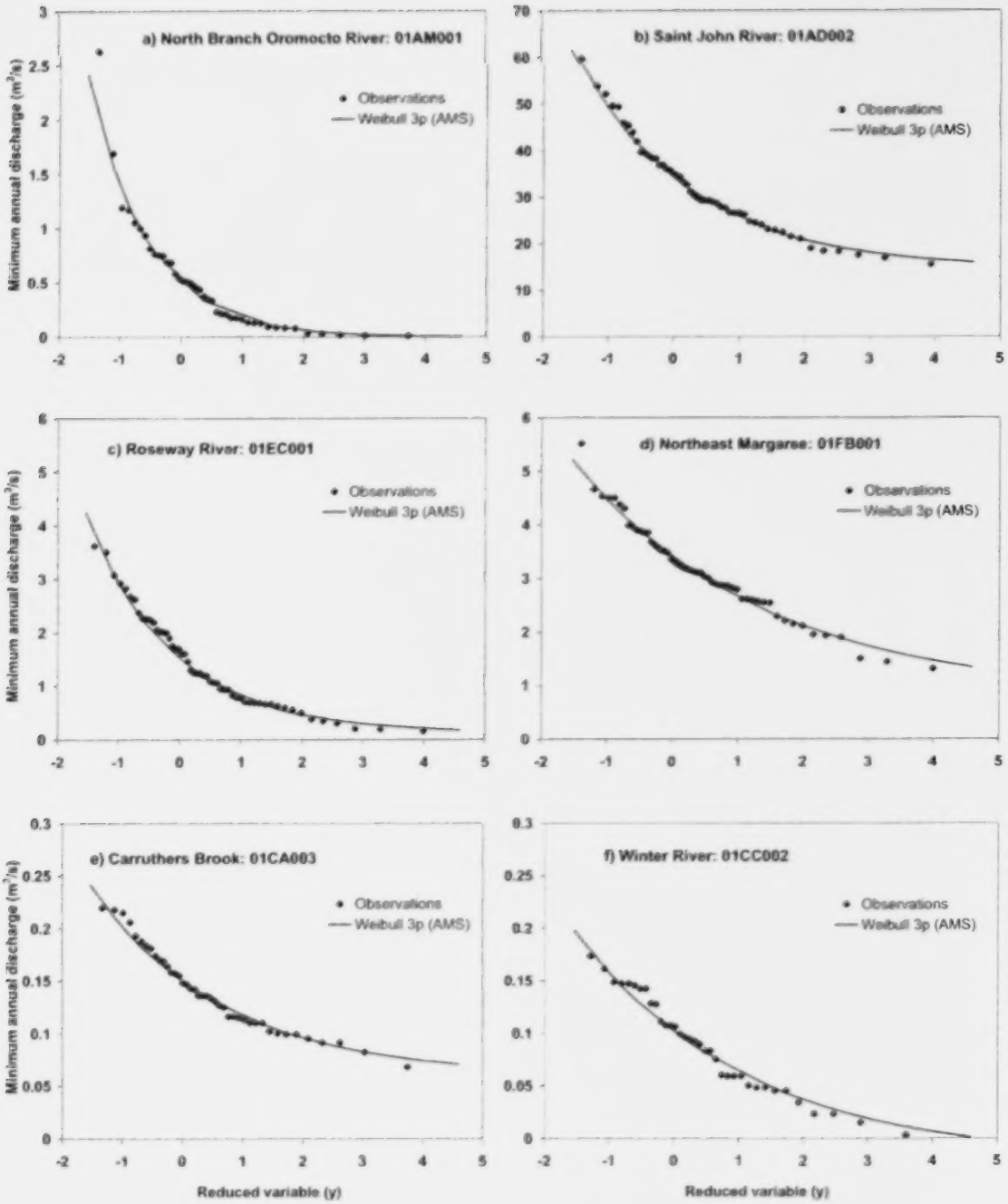

Figure 12. Examples of low flow frequency plots for selected stations throughout the Maritime Provinces (data are plotted using a Gumbel paper; AMS = annual minimum series).

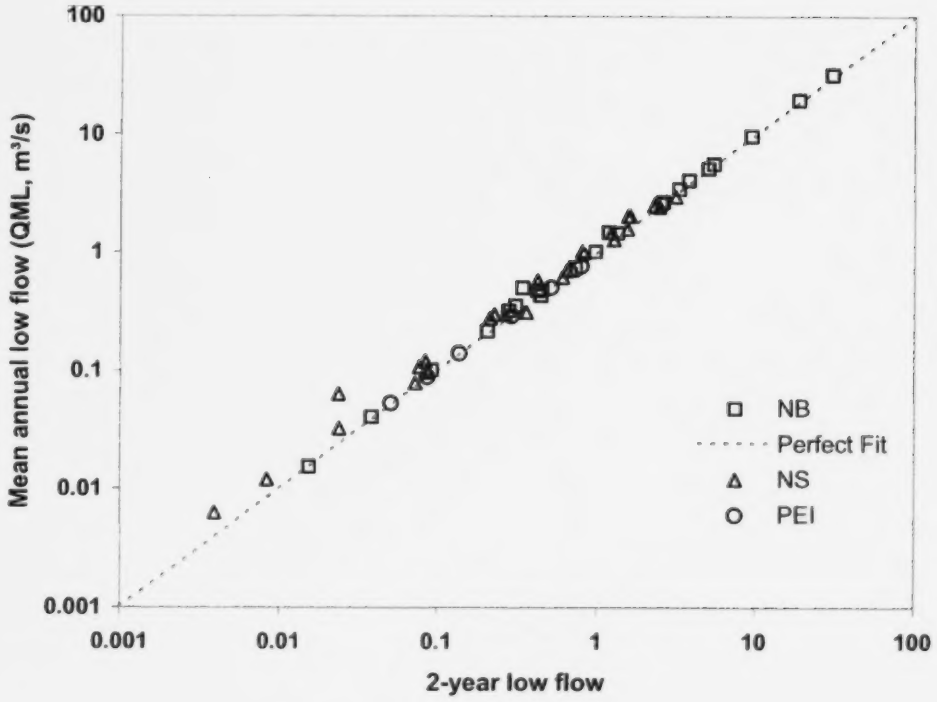

Figure 13. Plot of the mean annual low flow vs. the 2-year low flow for all the analysed stations throughout the Maritime Provinces.

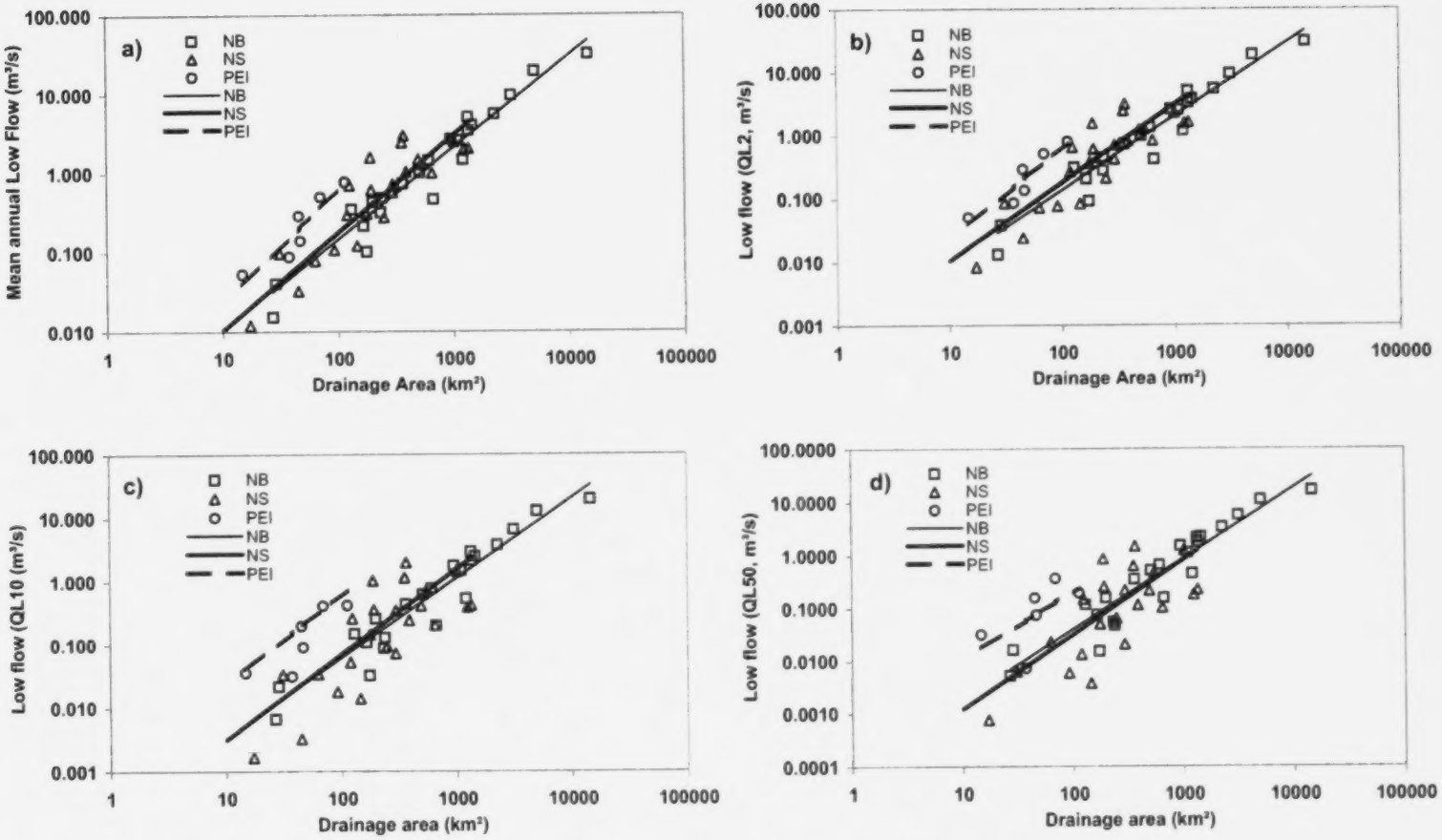

Figure 14. Relation between low flow data and the drainage area throughout the Maritime Provinces, a) mean annual low flow, b) QL2, c) QL10 and d) QL50.